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TECHNICAL REPORT

550-003-03H

CONFERENCE ON STOL TRANSPORT AIRCRAFT NOISE CERTIFICATION

JANUARY 30, 1969

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Noise Abatement
Washington, D. C. 20590

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FEDERAL AVIATION ADMINISTRATION
OFFICE OF NOISE ABATEMENT
Technical Support Staff
Washington, D. C.

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PREFACE

The proceedings of the First Industry/Government Conference on STOL Transport Aircraft Noise Certification are recorded in this publication. The conference was held in the Federal Aviation Administration's Headquarters on January 30, 1969, and attendance was available to all groups interested in the orderly development of STOL commerce. Organization of the conference was accomplished under the management of the FAA's Office of Noise Abatement with the support and close cooperation of the National Aeronautics and Space Administration.

The objective of the conference was to initiate activities which will result in an interchange of information and proposals which could serve as the base for STOL transport noise certification criterion. As such it is hoped that these proceedings will be considered as a departure point for the forthcoming noise rulemaking activities. Since the presentations at the conference were by members of the FAA and NASA, it is apparent that the comments tend to reflect a Government bias, however, it is our intent to provide an opportunity for all concerned parties to contribute to the formulation of the future STOL noise rule. Further, it is considered fortunate that we have the opportunity to jointly address the problem of STOL noise now with a constructive approach rather than later with, at best, a remedial approach.

The conference proper was structured after the classical acoustician's method of problem analysis; i.e., by seeking solutions at the source, related to the transmission path, and eventually in the vicinage of the receiver. The source mechanisms in some cases are many years old and we will need new ideas and techniques to provide solutions. In other cases, the acoustic mechanisms are new and acoustic control can be developed concurrent with vehicle development. The transmission path acoustic problems are in general amenable to solution through flight operational techniques and air traffic control procedures. It is in this area that STOL aircraft have great potential. The acoustic problems at the receiver are always complex. In the case of STOL aircraft, a new dimension of complexity is added because of the fact that operations in both urban and suburban environments are anticipated. The presented papers at the conference explored these problems in depth consistent with the time allocated to each speaker during the one day conference. Accordingly, there is need for further development of the considerations here presented. The printed papers were not edited and are the presentations of the respective speakers and as such, are expected to initiate thoughtful consideration of the STOL noise problems in their respective areas.

Definitive responses, as outlined by Mr. I. H. Hoover in his concluding remarks, are expected from concerned industry and community members. It

is expected that these responses will lead to the formulation of a working STOL transport noise certification task force and that they will provide guidance for that task force. Finally, it is anticipated that this effort will result in the development of noise certification criterion which will be equitable and advance the growth of an economically viable STOL transportation system.

JOHN O. POWERS, Chief
Technical Support Staff
Office of Noise Abatement
Federal Aviation Administration

OPENING REMARKS

by

George S. Moore
Associate Administrator for Operations

Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

CONFERENCE ON STOL TRANSPORT AIRCRAFT NOISE CERTIFICATION

Welcome to FAA. And welcome to this first industry-wide conference on STOL Transport Aircraft Noise Certification.

I'm sure everyone here this morning knows that FAA has just recently issued its first rulemaking proposal concerning aircraft noise certification. But let me recap, for just a minute, some of the history leading up to this proposal.

After several years of mounting public concern, including several hearings up on the Hill, Congress, last July, enacted Public Law 90-411. It was, and is, a landmark piece of legislation. It requires FAA to prescribe rules for the control and abatement of aircraft noise. Sounds simple, but I needn't tell this group it's not.

It's long overdue and very much in the public mind these days. And that's where we come in.

Anyway, Congress passed the law. It was the basis and the authority for the Notice of Proposed Rule Making which I mentioned a few minutes ago. The proposal may be changed somewhat as a result of comments we are now receiving. The deadline for public comment is March 12, 1969. We will then issue a final rule and it will set a precedent for the future.

Obviously, it is just the first step. It pertains only to new, large, transport category aircraft. But that's because we took on the most urgent problem first. The law does not overlook any category of aircraft. STOL's day is coming. And that's why you're here today. The purpose of this conference -- if I may use a currently popular phrase -- <u>to get a dialogue started</u>.

Realistic noise criteria are needed for STOL aircraft. For your benefit as well as the public's, the sooner the better. Neither government nor industry can afford to let STOL aircraft further escalate the noise problem. As a matter of fact, local communities won't allow it. And they are the ones who ultimately decide whether or not STOL ports will be built in their neighborhood.

Much has been said about the bright future of STOL aircraft. We agree. But there are some "IFs." One of the biggest is <u>if</u> STOL development can proceed uninhibited by the fear of greater noise pollution.

In your discussions today, I think you should avoid trying to precisely define the types of aircraft which are to be categorized as STOL aircraft. I say this because current airworthiness standards for powered-lift type

STOL aircraft are considered "tentative," design criteria for metropolitan STOL ports are termed "interim," and there is no standard definition for the word "short." <u>Therefore</u>, for the purposes f this conference, I would suggest that you refer to STOL aircraft as those aircraft that are capable of (1) taking off and landing on runways of limited length, (2) of climbing and approaching at steep angles, (3) deriving a substantial portion of their lift and control from power.

It is not our intention to discuss rotor craft in any detail because we believe that the noise characteristics of these aircraft are unique enough to require separate consideration.

While many of the rotor craft are capable of operating in a STOL mode, the criteria for their noise certification will be treated in a separate action. Small aircraft also are comparable in many operating aspects to STOL aircraft.

However, for those of you who are interested in noise as it relates to the development or operation of small aircraft should find today's discussions to be most interesting.

Again, it is the hope and desire of the agency that STOL aircraft are economically viable and socially acceptable. As you begin the activities today, you should keep in mind that the main objective of aircraft noise certification is to insure that noise will not be an inhibiting factor when STOL ports are introduced in urban and suburban communities.

Our experience over the last decade with jet aircraft leads us to conclude that it would be foolhardy -- if not a breach of the public trust on our part -- if we failed to recognize the seriousness of the noise problem in the development of STOL aircraft. But it doesn't stop there. We also must take positive steps to minimize noise at the very earliest stages of development. If we don't, we may not only inhibit the potential for commercial STOL operations -- we could kill that potential by default.

In closing, I want to thank the members of the National Aeronautics and Space Administration who have generously given of their time in support of this conference.

I hope you have a productive and interesting day.

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THE FEDERAL AVIATION ADMINISTRATION ROLE IN STOL DEVELOPMENT

by

Mrs. Joan B. Barriage
Aircraft Development Service

Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

THE FEDERAL AVIATION ADMINISTRATION ROLE IN STOL DEVELOPMENT

The fact that we are here today means that we are moving beyond the study phase; i.e.,

- Studies of vehicles
- Studies of systems
- Studies of markets
- Studies you have done
- Studies we have done

Now we are getting down to the business of bringing STOL transportation into being. Noise certification is one of the steps which industry and government must take together to resolve questions of what is required in aircraft design, aircraft operation, STOL port siting and design.

The impetus to getting STOL appears to be the economic squeeze of congestion. As a result, we may see STOL transportation getting started by using STOL runways at the major airports, but this is only a part of the potential environment. STOLs must move into their own facilities. Facilities much closer to the public than generally possible with the major airports that take hundreds and thousands of acres. Because of a significant number of people traveling to and from downtown, the first place we look for a site is downtown but perhaps the land availability and market will force us to the suburban area as well; then the noise differential may be much greater so the problem much worse. Our agency considers the noise problem second only to safety. From the design standpoint, we expect you must conclude that designing for noise reduction is as important as your designing for vehicle performance. As I indicated, noise certification is one of the steps; we are also developing airworthiness, certification and operational requirements, airspace procedures, airport design standards and navigation equipment such as the instrument approach system. The R&D to support this effort includes R&D in aircraft flight characteristics, flight operations, navigation systems, etc.

Why are we so interested in STOLs? Because we see it as a means of relieving congestion at airports and providing convenience in air travel for the millions of people who travel only a few hundred miles. With the STOL development supported by the high density travel areas, we can expect STOLs to move into many smaller cities and provide fast convenient air transportation where the expenditure in funds needed for large airports or extensive surface networks is not available.

We know STOLs are technically feasible but to be economically feasible there must be simultaneous development of the ground and airspace facilities.

As always, new aircraft set in motion changes to the Airport Systems, but today, as never before, the airports are choked off and organized community groups are revolting against further noise and smoke intrusion. This atmosphere of thought makes the development of any airport, including STOL ports, extremely difficult. Unless we can show the public that STOL aircraft are quiet neighbors, it may prove impossible to expand STOL into its prime market area. Studies and planning for STOL ports are underway in some of the metropolitan areas. If noise and pollution were not a problem, STOL port siting would be quite feasible in many areas of a city because the length of the facility would be relatively short, the funnel of airspace would be relatively small because of the steep approach and climbout, the offset approach, and the low tight turn capabilities of the aircraft.

In addition, advancements being made in area navigation and the instrument approach system may facilitate operating the aircraft along devious routes so as to minimize noise exposure to noise sensitive areas.

As an indication of what we expect the aircraft operation generally to be, here is a short film of 7 $1/2^{\circ}$ approaches by two transport aircraft tested at the National Aviation Facility Experimental Center. Three mile intercept and two miles on the glide slope were part of the test setup at NAFEC and the pilot removing his hood at 200 feet for a visual landing.

NOISE STUDY OF TRANSPORT DESIGNS

by

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Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

NOISE STUDY OF TRANSPORT DESIGNS

Introduction: NASA contracted with the Boeing Company (Vertol), Ling-Temco-Vought, Inc., and Lockheed-California Company to study the technical and economic feasibility of V/STOL concepts for short haul commercial transport aircraft. Results are available in NASA contractor reports CR-670, CR-743, and CR-902. The purpose of the studies was to determine which of the various V/STOL concepts were the most promising for development into successful commercial short haul transports and to identify the near term research required to develop the aircraft. The studies included some theoretical analyses of the noise generating characteristics of the various V/STOL aircraft designs. This presentation reviews some of the study results with emphasis on the noise characteristics of STOL aircraft.

Figure No. 1: A three-view drawing of a typical turboprop STOL design is shown. A family of turboprop aircraft were designed for VTOL, V/STOL, and STOL with commercial field lengths of 1000 and 2000 feet. The approach airspeed of the STOL designs for 1000 and 2000 foot field lengths was 55 and 85 knots respectively. Aircraft that were designed for a pure VTOL mission will not be discussed. However, V/STOL aircraft will be discussed because V/STOL aircraft are representative of STOL aircraft having very high performance. The tilt wing feature shown in Figure No. 1 was not unique to the V/STOL designs; for example, the 1000 foot field length STOL aircraft utilized 20 degrees of wing tilt. Turbojet engines were installed in the aft fuselage (not shown) for pitch control. The number of pitch engines, which were a major source of noise, depended upon the field performance of the STOL aircraft, i.e., the V/STOL design required two pitch engines, the 1000 foot STOL required one pitch engine, and the 2000 foot STOL required no pitch engines.

Figure No. 2: A typical fan-in-wing V/STOL design is shown. Aircraft were designed for a 500 statute mile range and payloads corresponding to 60 to 120 passengers. Figure No. 2 shows the "pure" or classical fan-in-wing concept in which the same turbojets are utilized to drive the tip-turbine lift fans and to provide thrust for cruise flight. The pitch fan in the nose of the fuselage was incorporated in the 1000 and 2000 foot field length STOL designs as well as the V/STOL design shown. Due to airframe-propulsion system integration problems the fan-in-wing V/STOL design gross weight was 79,000 pounds compared to 62,000 pounds for the turboprop V/STOL. However, though this particular fan-in-wing concept was heavy, it featured some favorable noise generating characteristics as presented later.

Figure No. 3: A typical composite fan-in-wing 2000 foot field length STOL design is shown. The word "composite" herein means that separate propulsion systems were used to drive the lift fans and for cruise flight; in this case four turbojets mounted in the top of the fuselage were used to drive tip-turbine lift fans and two turbofans with a bypass ratio of three were used for cruise. Study design criteria limited propulsion

system technology to the 1970 time period. The cruise engines were diverted to provide lift in low speed flight. This feature reduced lift fan diameter and other system requirements such that airframe-propulsion system integration difficulties were significantly reduced. The result was a lighter design, compared to the "pure" fan-in-wing design, but it was also a noisier design because of the separate cruise propulsion system.

Figure No. 4: A typical jet flap 2000 foot field length STOL design is shown. Four 1.1 to 1.0 bypass ratio turbofans were used with one-half of the primary exhaust flow diverted through a ducting system to provide a momentum coefficient, C_u, of 0.2 over wing flaps, rudder, and elevator. The fan flow and one-half of the primary flow exhausted through vectoring nozzles. While the jet flap itself was relatively quiet, this jet flap aircraft configuration was very noisy because of the use of the small diameter, multiple vectoring nozzles. Side studies showed that use of increased bypass ratio turbofans would have reduced gross weight, DOC, and noise, so this jet flap design is included herein only for presentation of a sensitivity study.

Figure No. 5: A typical cruise fan 2000 foot field length STOL design is shown. The design features externally blown flaps; in this case during low speed flight the exhaust from the cruise fans is directed over wing trailing edge double-slotted flaps. The cruise fan 2000 foot STOL was much quieter than the jet flap 2000 foot STOL and was also competitive noisewise with lift fan aircraft. One disadvantage of this externally blown flap STOL design, however, was that large weight and economic penalties were realized as field length capability was reduced from 2000 feet.

Figure No. 6: The attenuation of the perceived noise levels of various STOL designs is presented. The ordinate is PNdB which is the classical frequency-weighted sound pressure level - not effective PNdB which includes corrections for pure tones and other parameters. The theoretical predictions of the perceived noise levels of the various study designs fall within the boundaries shown. The figure shows that (1) at distances less than about 2000 feet, the propeller aircraft (including rotor V/STOL designs) generated less perceived noise than fan aircraft, (2) at about a 2000 foot distance the perceived noise for all the various aircraft was about the same, and (3) beyond about 2000 feet the lift fan aircraft generated less perceived noise than the other aircraft. This is because high-frequency noise attenuates at a greater rate than low-frequency noise, and the lift fan aircraft generated the higher frequency noise. Maximum perceived noise limits of about 68-70 PNdB have been suggested for residential areas at night. Based on a 70 PNdB limit, lift fan STOL aircraft could operate several miles closer to residential areas than the propeller or rotor STOL designs. The significance of the attenuation characteristics shown in Figure No. 6 depends upon the degree to which

the absolute noise levels can be reduced in the future but, for some aspects of the noise problem, Figure No. 6 illustrates that propeller aircraft require the largest noise reductions.

Figure No. 7: Ninety PNdB contours are shown for three STOL aircraft designs on the ground at takeoff power. These results, and all other results presented herein, are from theoretical analyses with predicted accuracies of from ±3 PNdB to ±6 PNdB. Despite these possible large errors in absolute perceived noise levels, experimental results are slowly being accumulated which substantiate the theoretical results of this presentation. Some of these experimental results will be presented by Dave Hickey in a following presentation. Figure No. 7 shows that a high performance STOL (i.e., V/STOL) "pure" fan-in-wing design, which is heavier than the turboprop design, is competitive acoustically with the turboprop designs. The difference in the 90 PNdB contours for the two turboprop designs is due to the differences in installed power and because the V/STOL design has two pitch engines in the aft fuselage compared to no pitch engines for the turboprop STOL designed for a 2000 foot field length.

Figure No. 8: For the same three aircraft of Figure No. 7, Figure No. 8 shows 90 PNdB contours that correspond to a takeoff followed by a 20 degree climbout with full takeoff power utilized throughout the climb. The fan-in-wing V/STOL design has the smallest footprint, but even it is a large footprint in the context of operation from a city center. For the turboprop 2000 foot STOL, an area roughly two miles by three miles is subjected to 90 PNdB or more. For the fan-in-wing aircraft the boundary is about one mile by two miles.

Figure No. 9: Ninety PNdB contours that correspond to a landing with a 10 degree approach path are shown. Figure No. 9 illustrates that noise generation for the landing case is significant but less severe than for the takeoff case shown in Figure No. 8. Figures No. 7, 8, and 9 illustrate the need for large noise reductions for all STOL designs if near city center operations are to be realized. Not illustrated by figure were results predicted for cruise flight with the aircraft in level flight at an altitude of 2000 feet above the observer. Perceived noise levels were 100 ± 5 PNdB for a wide variety of V/STOL and STOL designs. It thus appears that noise generated by STOL aircraft during flight at relatively low altitudes is another significant aspect of the noise problem.

Figure No. 10: The effect of design propeller tip speed on block speed, gross weight, direct operating cost, and perceived noise level are presented for a turboprop 2000 foot field length STOL aircraft. The ground rule for this sensitivity study was to maintain aircraft mission capability including field performance while reducing propeller tip speed from the originally selected value of 900 fps to 700 fps to assess potential noise reductions. Wing-loading and thrust-to-weight ratio were held constant.

Accompanying the reduction in propeller tip speed were an increase in propeller activity factor, increased propeller weight, increased gear box and associated drive system weights (due to increased torque), increased engine size and weight, etc. As propeller tip speed was reduced, Figure No. 10 shows block speed increased (due to increased thrust available for cruise at constant static thrust-to-weight ratio), gross weight increased, DOC for a 500-mile stage length decreased due to the impact of block speed, while perceived noise as received by an observer in line with the take-off path and 5000 feet from the brake release point remained essentially constant. (At a point 500 feet from the aircraft at brake release the perceived noise levels also remained essentially unchanged as presented later). Thus, for this particular design, it was found that reducing propeller tip speed reduced the propeller noise but increased engine noise with an overall result that little was achieved acoustically. This sensitivity study thus raises a red caution flag and illustrates that potential noise reductions must also be studied in the context of the complete aircraft designed for a given mission.

Figure No. 11: The effect of static thrust-to-weight ratio on block speed, gross weight, DOC, and perceived noise level are presented for "pure" fan-in-wing STOL aircraft. The static thrust-to-weight ratio was varied over a range corresponding to field length capabilities from about 1000 to 2000 feet as shown. Mission range and payload were maintained for this parametric family of fan-in-wing STOL aircraft. As field length was decreased from 2000 feet to about 1000 feet, (1) block speed increased due to increased thrust available, (2) gross weight increased due to increased engine size, tail areas, etc., (3) direct operating cost increased despite the impact of block speed because of increased gross weight and a significant increase in propulsion system cost, and (4) perceived noise levels at the 5000 foot point from brake release decreased in favor of the higher thrust-to-weight ratio STOL aircraft because of the effect of increased distance between the aircraft and the observer. At the 500 foot distance from brake release, the perceived noise levels for this family of fan-in-wing STOL aircraft remained about the same because the main source of noise was fan blade passage noise which was predicted to be essentially the same for both aircraft. Figure No. 11 illustrates that noise reductions may be accompanied by economic penalties.

Figure No. 12: The effect of static thrust-to-weight ratio on block speed, gross weight, DOC, and perceived noise level are presented for the jet flap STOL design. This sensitivity study was similar to that described for the fan-in-wing aircraft, Figure No. 11, and the results are also similar; namely that increasing the thrust-to-weight ratio decreased perceived noise levels at 5000 feet from brake release but substantially increased the direct operating cost of the jet flap STOL aircraft.

Figure No. 13: A summary of the sensitivity studies, Figures No. 10, 11, and 12, plus additional sensitivity studies conducted on two rotor V/STOL aircraft designs are presented. The figure is largely self-explanatory with the added note that the perceived noise level tabulation headed "At Brake Release" is for a 500 foot distance from the aircraft in the direction of peak intensity with the aircraft static on the ground at take-off power. Examination of Figure No. 13 reveals that, for the five types of V/STOL and STOL aircraft shown, the studies that were conducted to assess the sensitivity of far-field perceived noise to parametric changes in aircraft design were either unsuccessful in reducing perceived noise levels or reductions in perceived noise levels were accompanied by significant economic penalties.

In conclusion, noise reductions may be achieved by (1) parametric aircraft design optimization, (2) aircraft operational considerations and techniques, and/or (3) application of noise reduction techniques at the noise source. Each of these is important. However, to achieve the major reduction in noise which is needed for all types of STOL aircraft, Figure No. 13 and other results presented herein suggest that the best approach to noise reduction is to continue to increase knowledge of noise source characteristics to permit the application of effective noise reduction techniques at the noise source. This approach to noise reduction will be the subject of several of the presentations to follow.

TYPICAL TURBOPROP AIRPLANE

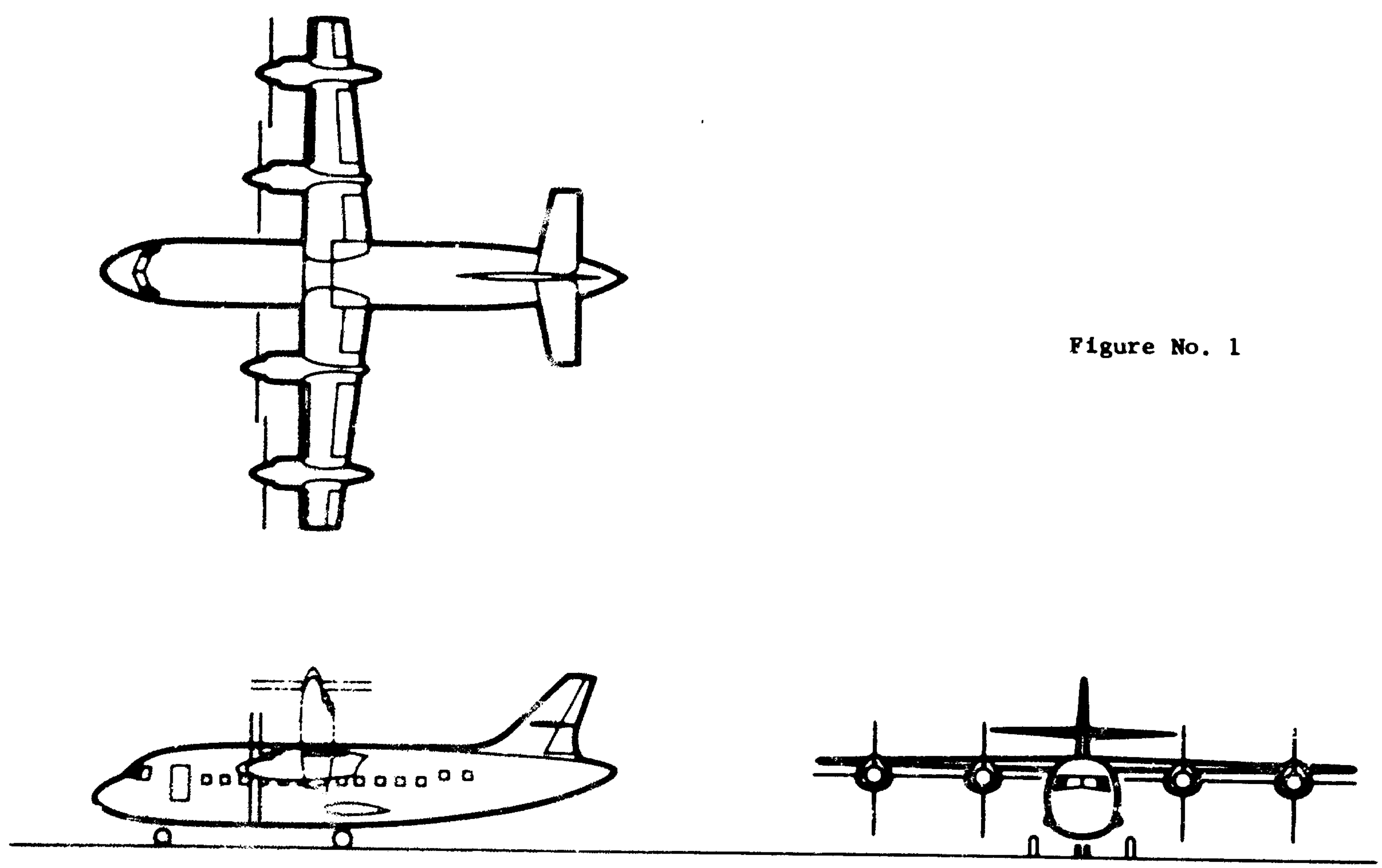

Figure No. 1

TYPICAL FAN-IN-WING AIRPLANE

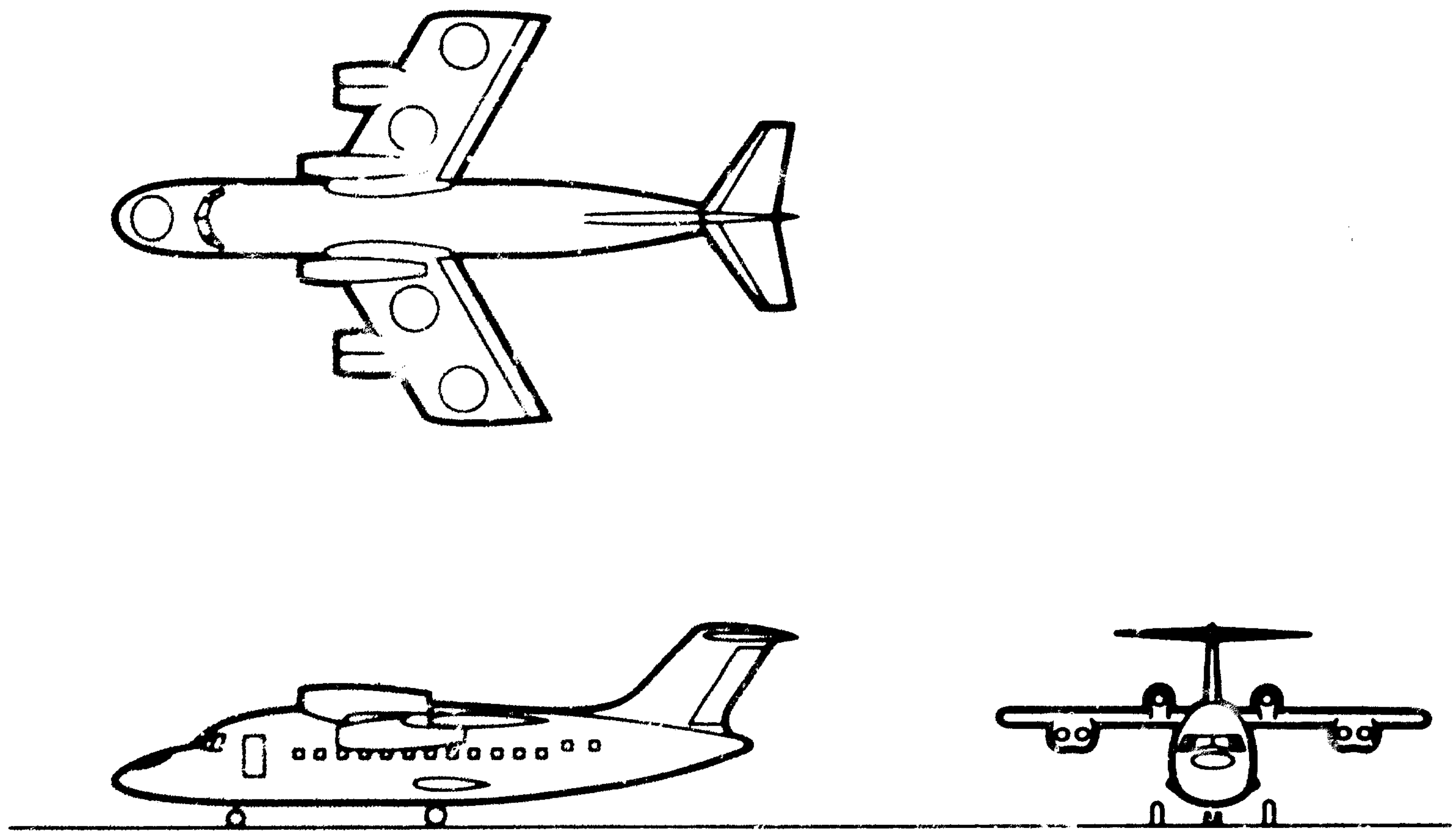

Figure No. 2

FAN-IN-WING STOL AIRCRAFT

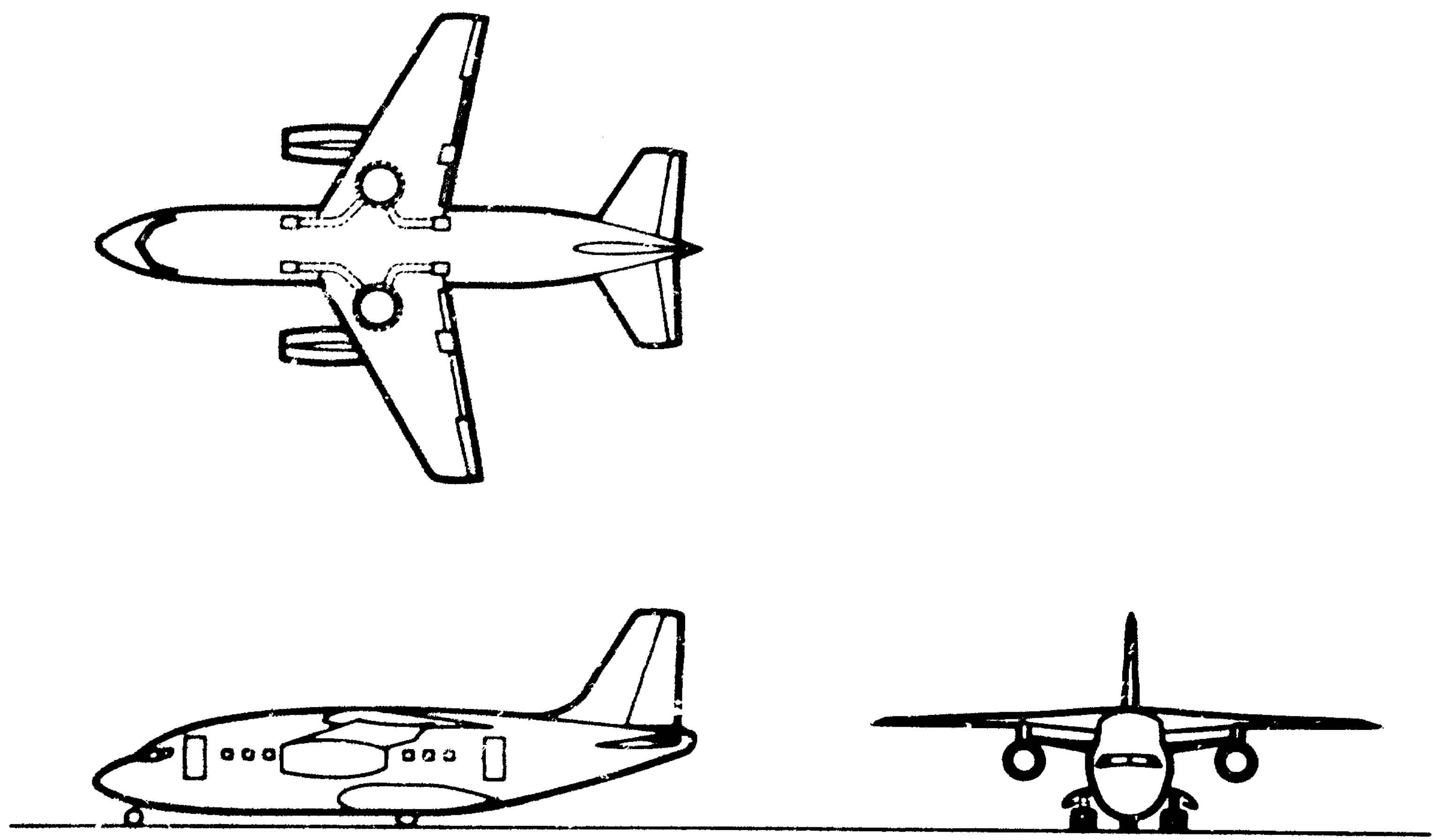

Figure No. 3

TYPICAL JET FLAP AIRPLANE

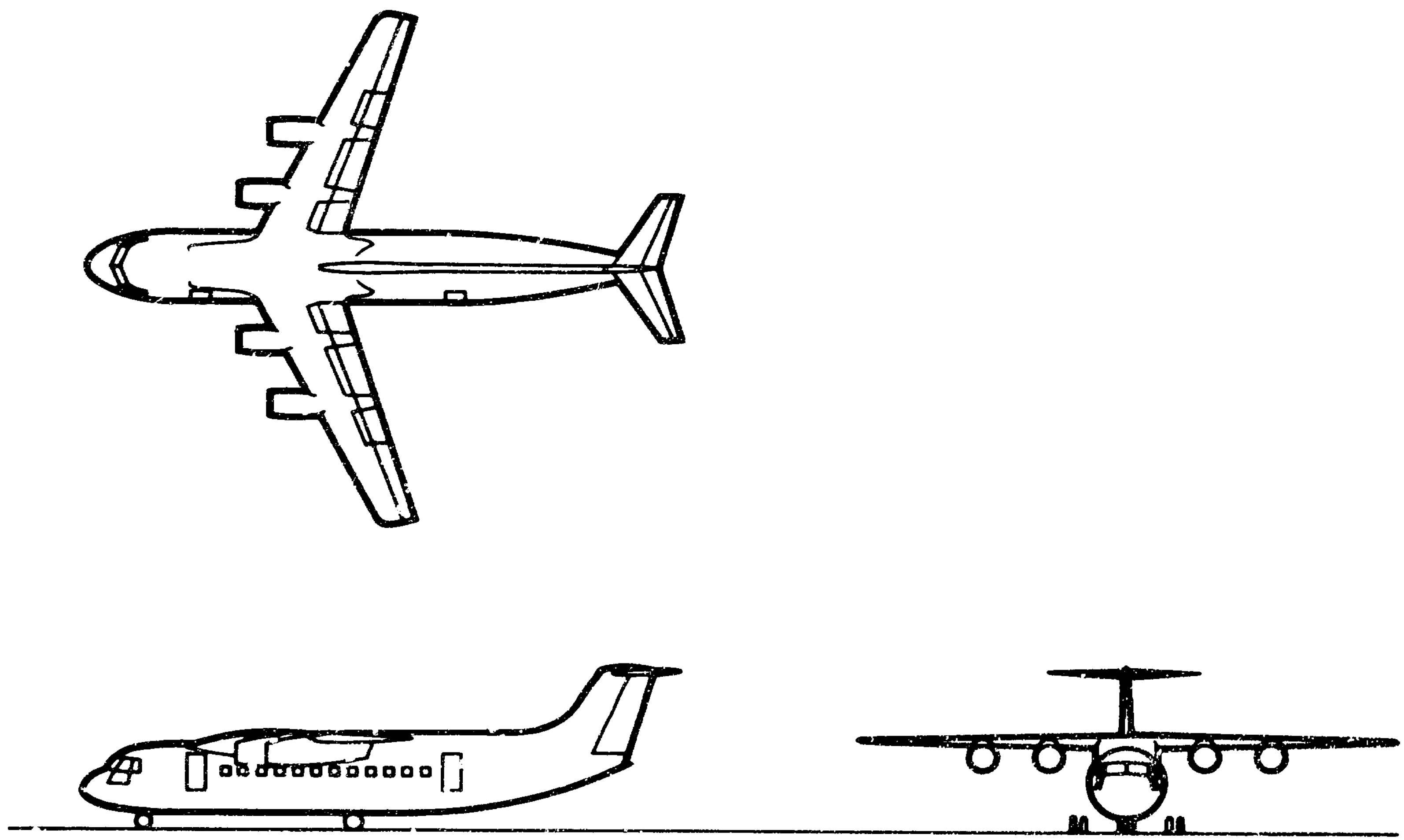

Figure No. 4

CRUISE FAN STOL AIRCRAFT

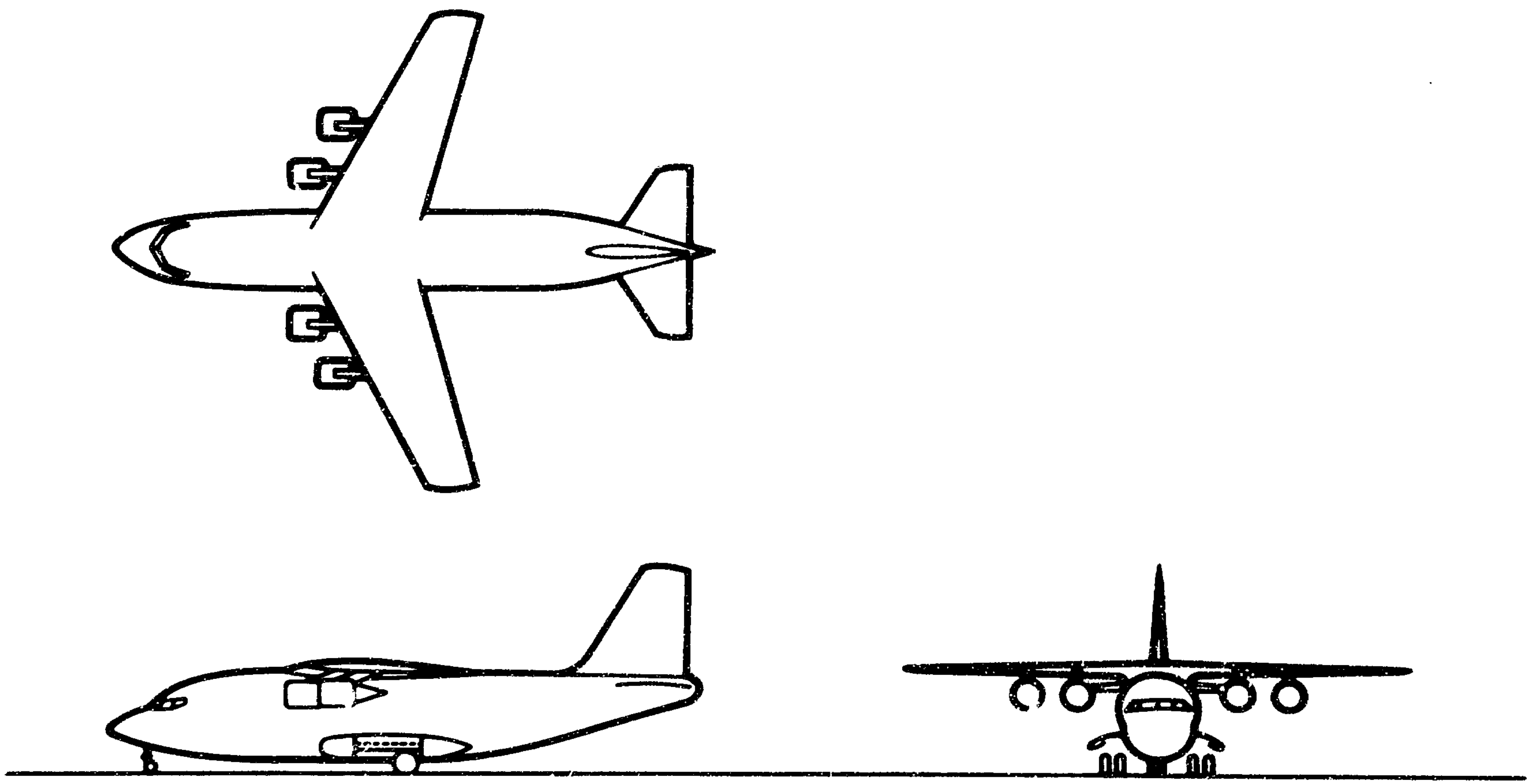

Figure No. 5

NOISE GENERATED BY STOL AIRCRAFT, 50 TO 95000 lb GROSS WEIGHT

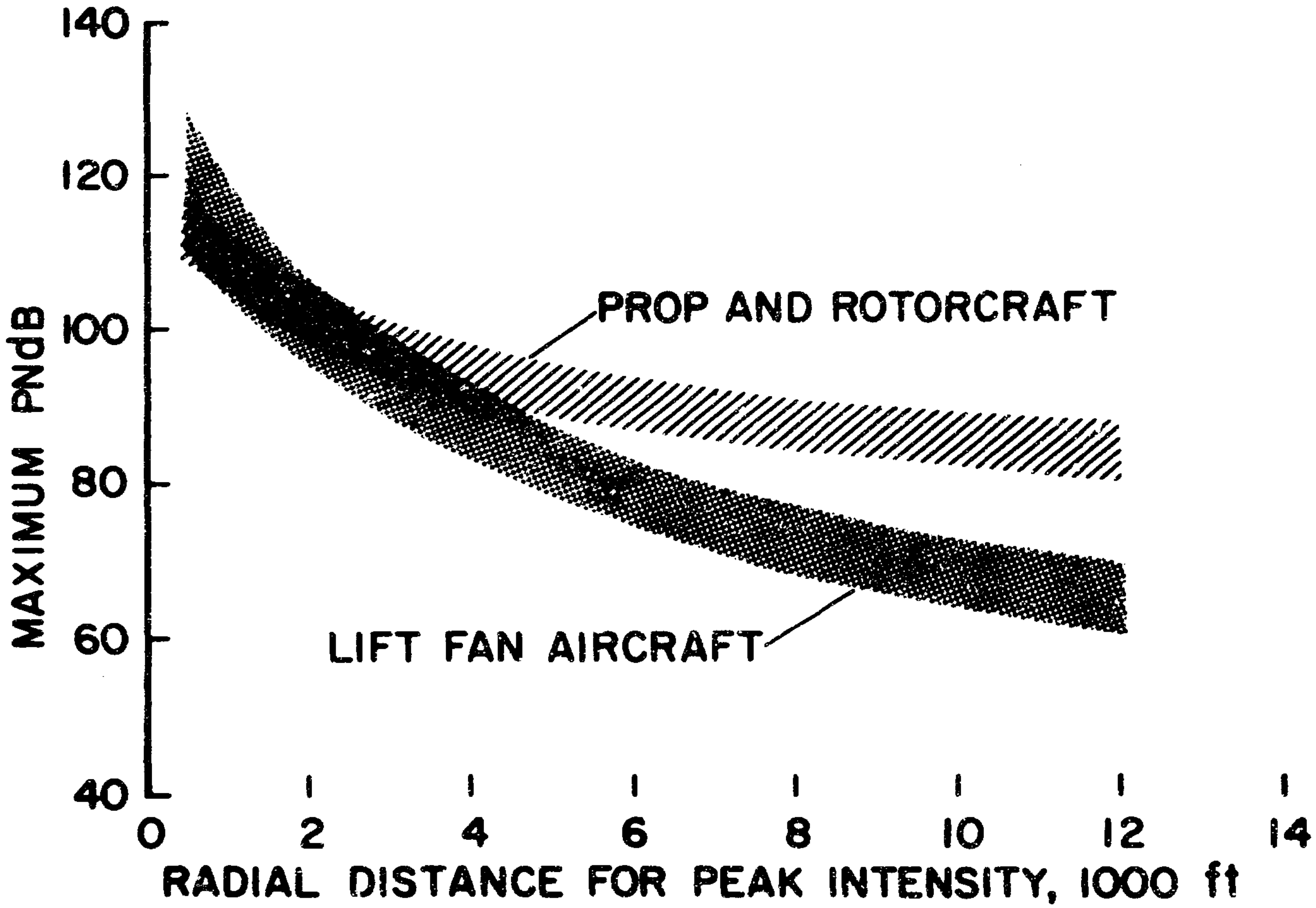

Figure No. 6

DISTANCE FOR 90 PNdB, ON THE GROUND, V=O

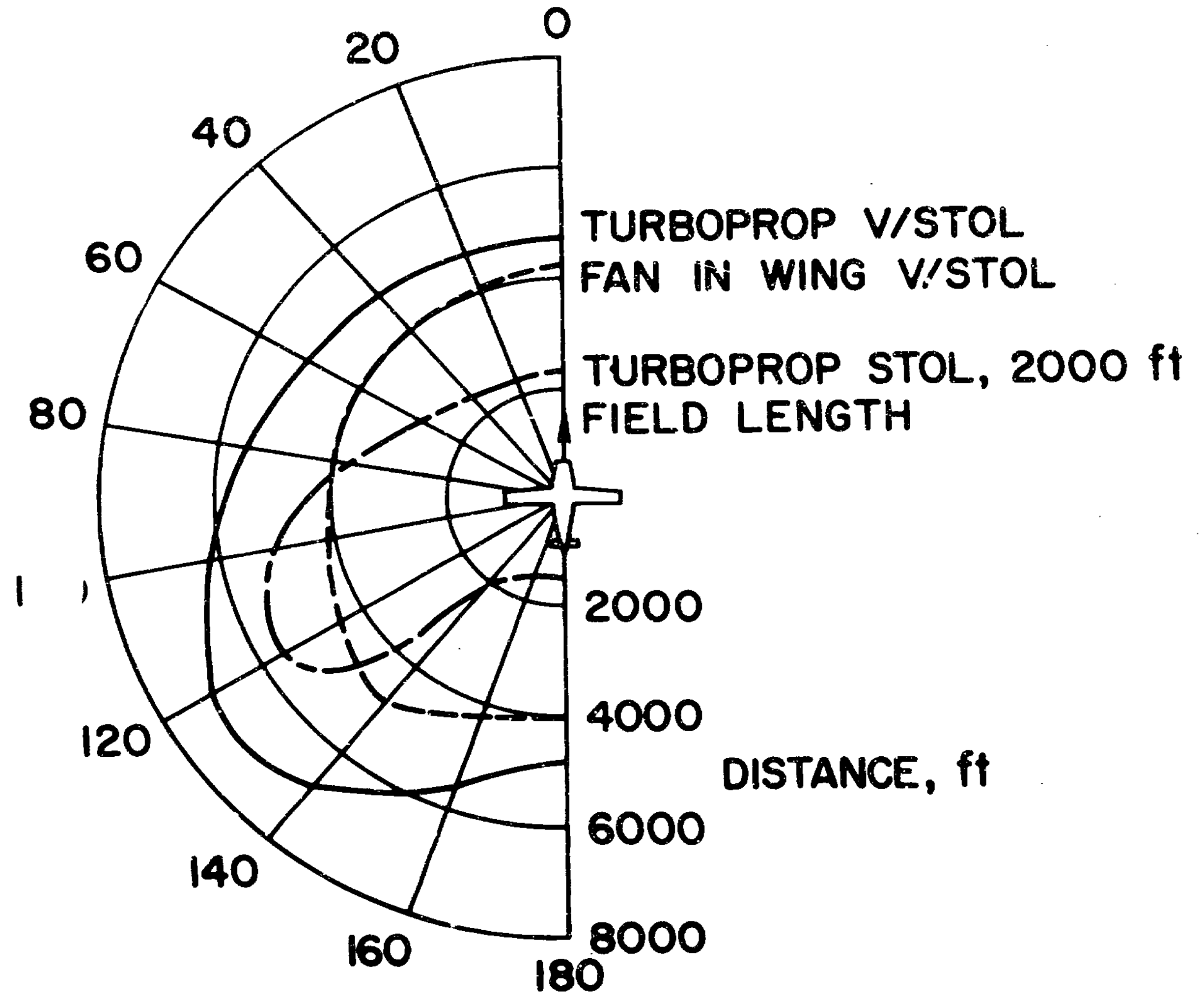

Figure No. 7

DISTANCE FOR 90 PNdB ALONG A 20° TAKEOFF FLIGHT PATH

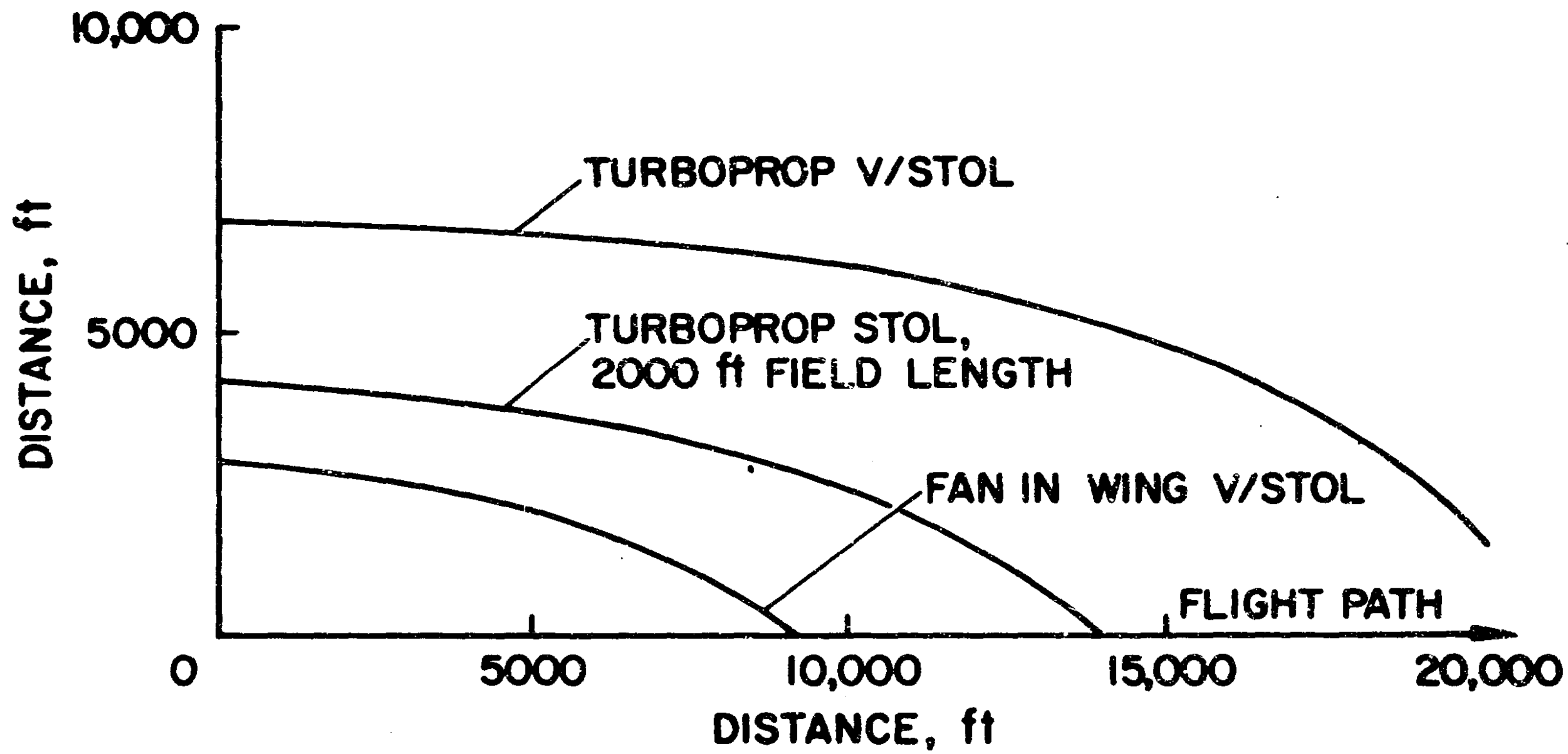

Figure No. 8

DISTANCE FOR 90 PNdB ALONG A 10° APPROACH PATH

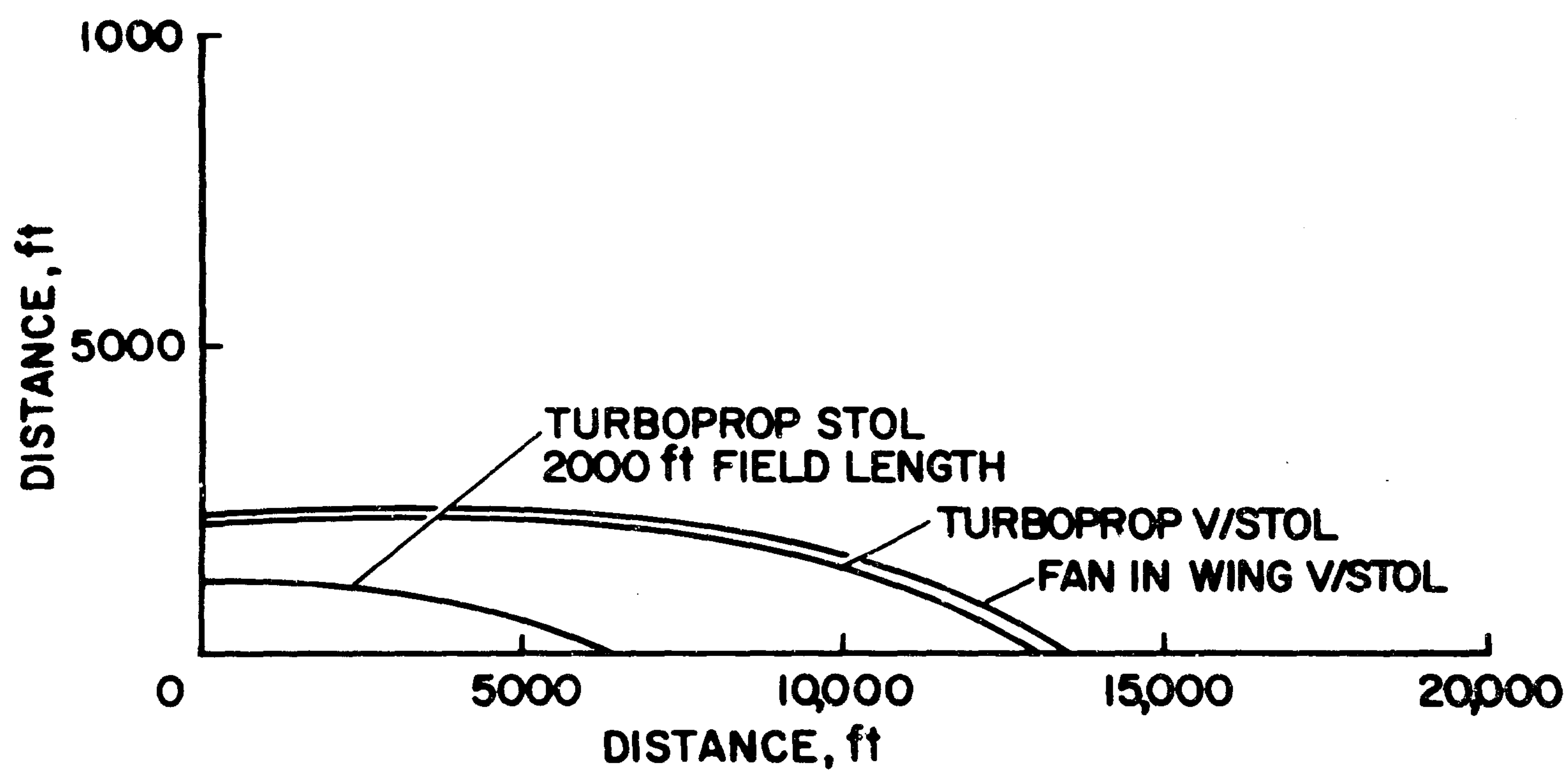

Figure No. 9

DEFLECTED SLIPSTREAM SENSITIVITY OF CHARACTERISTICS TO PROPELLER TIP SPEED

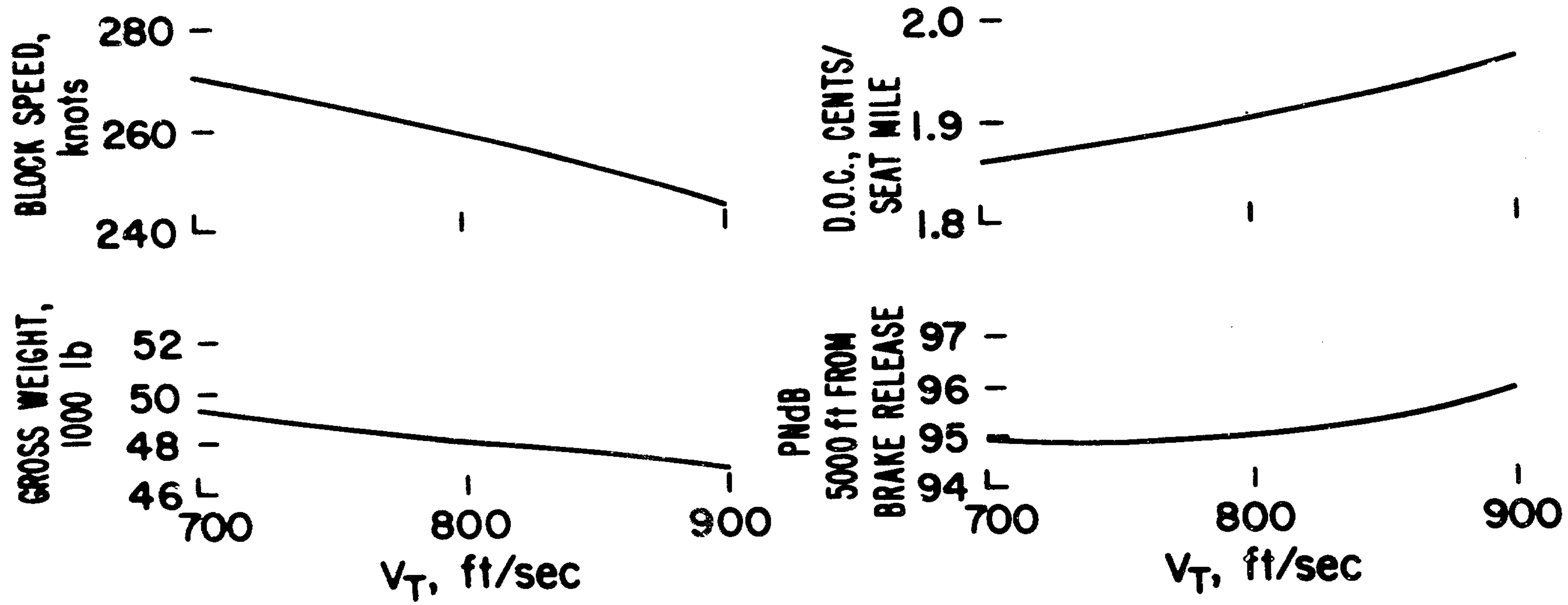

Figure No. 10

FAN IN WING SENSITIVITY OF CHARACTERISTICS TO T/W STATIC

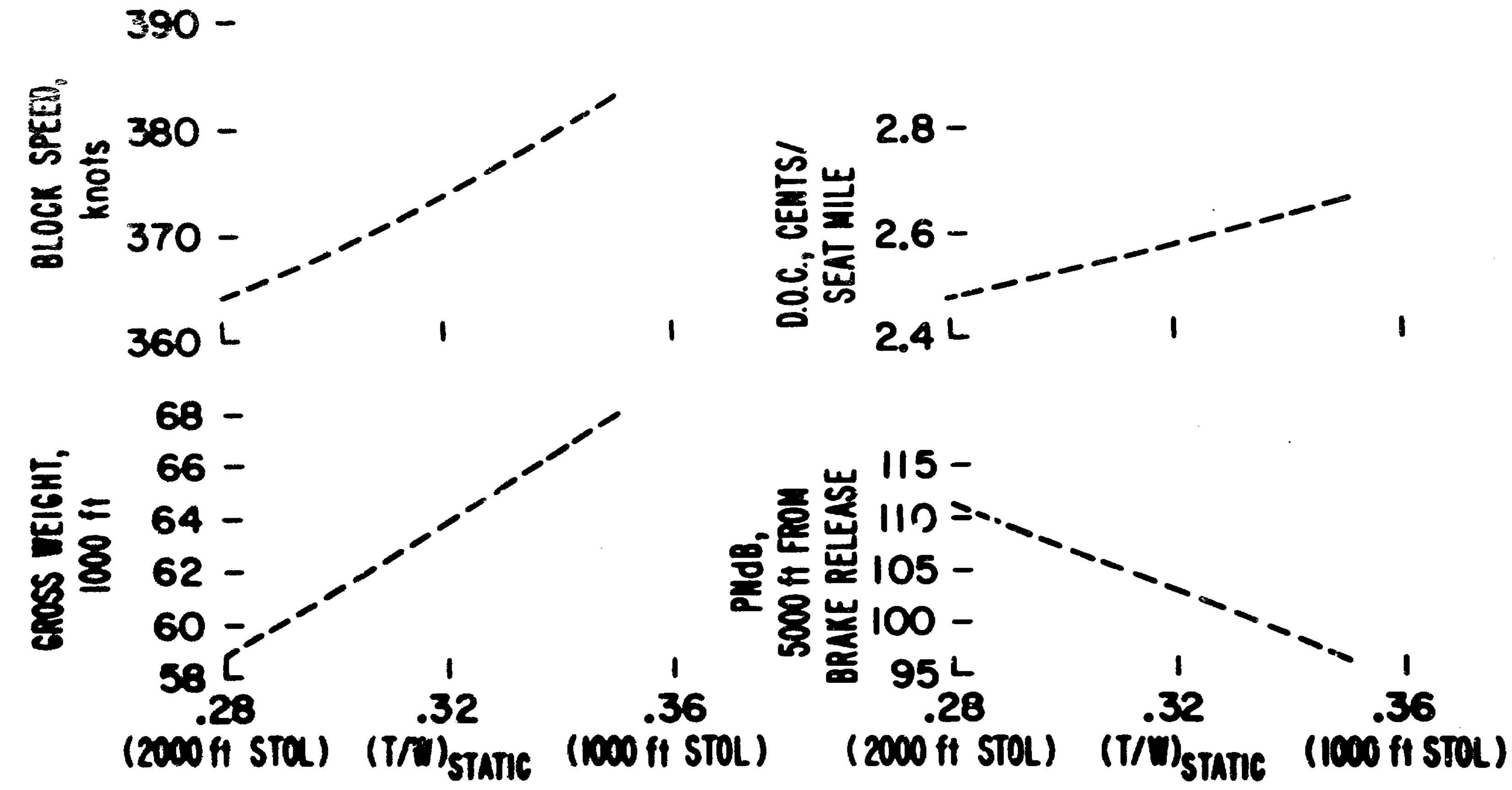

Figure No. 11

JET FLAP SENSITIVITY OF CHARACTERISTICS TO T/W_{STATIC}

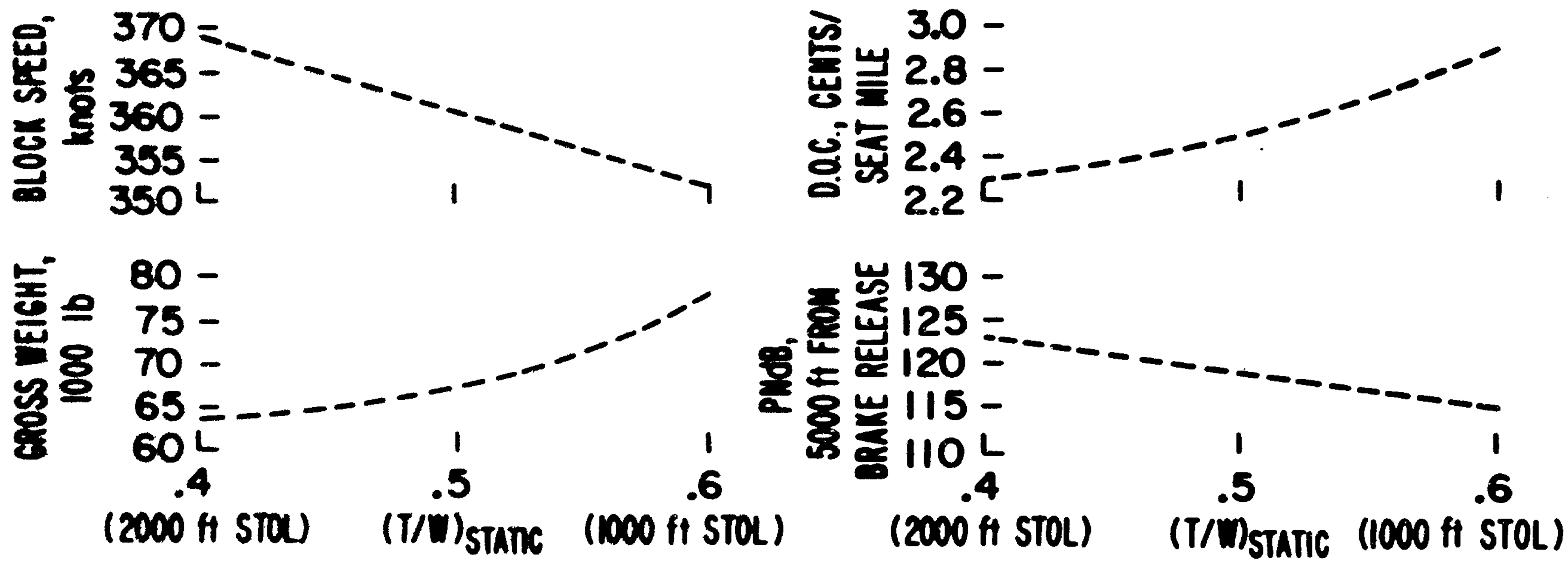

Figure No. 12

Figure No. 13

RESULTS OF THE NOISE SENSITIVITY ANALYSIS

AIRCRAFT TYPE	MODEL	D. O. C. (cents/ seat mile)	BLOCK SPEED (knots)	PERCEIVED NOISE LEVEL (PNdB) AT BRAKE RELEASE	PERCEIVED NOISE LEVEL (PNdB) 5000 ft FROM B.R.	ALTITUDE 5000 ft FROM B.R. (ft)
DEFLECTED SLIPSTREAM	900 fps	1.96	244	100	96	610
	800 fps	1.90	259	99	95	610
	700 fps	1.857	271	99	95	610
JET FLAP	1000-ft STOL	2.9	353	130	115	1335
	2000-ft STOL	2.3	369	128	123	570
FAN IN WING	VTOL	DOES NOT APPLY TO THIS STUDY				
	1000-ft STOL	2.67	383	105	96	690
	2000-ft STOL	2.475	364	105	111	322
TILT ROTOR	900 fps	2.67	296	111	98	1625
	800 fps	2.70	296	109	96	1620
	700 fps	3.09	291	108	93	1600
STOPPED ROTOR PROP	900 fps	2.65	312	109	95	1680
	800 fps	2.70	315	110	96	1690
	700 fps	3.12	322	109	94	1790

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NOISE SOURCE CHARACTERISTICS OF PROPELLERS AND ENGINES

by

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Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

NOISE SOURCE CHARACTERISTICS OF PROPELLERS AND ENGINES

ABSTRACT

Brief descriptions are presented of the main physical characteristics of the noise generated by propellers, reciprocating engines, and jet engines including both exhaust jet mixing and flow interaction noise components. Illustrations are given of the noise pressure time histories from the above sources. Also included are illustrations of the various types of noise spectra encountered in connection with the above sources and the significance of spectrum shape with regard to annoyance reactions. Low-frequency, broad-band, and discrete-tone spectra are discussed and are illustrated along with the shapes of the associated radiation patterns. Brief discussions are also included regarding the current status of theories and methods for predicting noise from the above sources and the atmospheric propagation losses as a function of distance from the sources.

INTRODUCTION

This paper contains a brief digest of information relative to the physical characteristics of some of the main noise sources of STOL vehicles. Based on experience, the propulsion units of the aircraft are the dominant sources of noise and hence the application of noise reduction procedures to them may affect the overall design and performance of the aircraft. Figure 1 contains a list of sources to be considered which are: propellers, reciprocating engines, and gas turbine engines, including both the straight jet and fan types. Other sources of noise such as accessories, gearing, etc., may in certain cases be significant from a noise standpoint but noise reduction procedures in these cases will involve mainly detail design considerations and thus should not markedly affect the overall performance of the aircraft.

The noise source characteristics to be considered are listed in figure 2. It goes without saying that the level of the noise is an important consideration in the design and operation of STOL vehicles. Other characteristics of the noise such as the spectrum, the temporal characteristics, the radiation patterns and time duration of exposure are of special significance and will also be considered.

GENERAL CONSIDERATIONS

Before considering the individual noise sources and their characteristics, there are some considerations of a general nature that should be noted.

Since annoyance reaction is a main consideration in the noise problem, it is well to keep in mind the characteristic annoyance reaction curve of figure 3. This curve represents equal annoyance levels as determined from jury tests. These results suggest the importance of spectrum shape. In general, it can be seen that high frequency noises of a given level are equally annoying as lower frequency noises at relatively higher levels.

Another consideration in the annoyance problem is the effect of atmospheric absorption during noise propagation. The characteristic noise attenuation curve of figure 4 is well known and has a characteristic shape. Generally, the higher frequencies are attenuated at a much faster rate than the lower frequencies. Thus, high frequency noise components which are an important consideration in annoyance at small distances may be substantially attenuated at very large distances. There are, however, many situations in STOL operations where the distances are not large enough to attenuate the noise sufficiently due only to atmospheric losses.

TYPES OF NOISE SPECTRA

The types of noise spectra encountered in the vicinity of STOL vehicles having various types of power plants can be characterized by the example spectrum envelopes of figure 5. The low frequency spectrum envelope curve is representative of many propeller driven aircraft. The noise from the propeller is generally greater at the lower frequencies except for the case of very high propeller tip speeds. Reciprocating engine intake and exhaust noises also follow a similar spectrum shape.

The broad band noise spectrum curve on the other hand is representative of jet engines for which the exhaust mixing noise or other sources of random noise are dominant. Spectra containing strong discrete tones may be associated with lift fans or with fan type power plants for which effective acoustic treatments have not been included. No particular significance should be attached to the relative vertical positions of these three envelope curves since they will each vary depending on the design and operational features of the particular power plant. In the next few figures, schematic diagrams are included to illustrate some of the physical properties of the noise from propellers, reciprocating engines and gas turbine engines.

Figure 6 illustrates the type of noise spectra associated with propellers. The top diagrams represent a relatively low tip speed condition. The discrete frequency components, associated with those aerodynamic loads on the blades which are harmonically related to the propeller rotational frequency, decrease in amplitude markedly as frequency increases. Vortex noise, associated with fluctuating viscous forces, which need not be harmonically related to the propeller rotational frequency, is identified as the broad band components at the higher frequencies. The noise pressure time history for such a low speed propeller has the gross features of a sine wave which recurs at a frequency corresponding to the blade passage frequency. The bottom sketches of figure 6 relate to a higher tip speed condition. The vortex noise is dominated by the rotational noise for which the higher harmonics are relatively stronger than at low tip speeds. In this high speed case, the noise pressure wave forms are more peaked in appearance and their peak factors are thus markedly greater than for those of the low speed propellers.

Figure 7 contains a sample noise spectrum for a turboprop power plant for which the propeller is the dominant noise producing component. It can be seen that only a few noise peaks are present, and these are harmonics of the propeller blade passage frequencies. Although not shown in the figure, the higher frequency components were reduced in amplitude to the point where they were not identifiable on the spectrum plot. These data are for a specific airplane installation, however, they are representative of many turboprop installations for which the accessory and exhaust noise components are of little concern.

In a conventional reciprocating engine-powered propeller installation, the engine noise can be comparable to the propeller noise and hence is of direct concern. Some sample data for such a power plant are shown in Figure 8. The solid line peaks represent propeller noise harmonics which occur at the blade passage frequency. The dashed line peaks represent the engine noise components which are integral multiples of the engine firing frequency. Several observations can be made. First of all a large number of engine frequencies are present, and some of these are noted to be of the same order of magnitude as the propeller noise components. There is, however, no systematic pattern of amplitude of the engine components as a function of frequency. This unusual amplitude pattern is the result of asymmetries in the geometry of the engine exhaust collector system. The result is that some pulse frequencies add in phase and some add out of phase. For the particular example shown a gear box was used. The engine frequencies thus were not integral multiples of the propeller shaft frequencies. Cases are encountered, however, where some of the engine frequencies occur at exactly the propeller blade passage frequencies thus making a noise source analysis very difficult. There is a further analysis complication in the case of a reciprocating engine. The intake noises occur at the same frequencies as the exhaust noises, and unless some special precautions are taken, the separation of noises from these two sources may not be possible. In comparing the data of this figure with those of figure 7, it is obvious that the use of a gas turbine drive unit is beneficial in essentially eliminating firing frequency noises.

The noise from gas turbine power plants varies considerably depending on the type of engine cycle, the operating conditions, and the position of the observer. The types of noise spectra encountered, however, can be represented schematically by the data of figures 9 and 10. The broad band noise components come either from the mixing of the exhaust jet with the ambient air or from the interactions of the air flows with the internal components of the engine. Tones are associated with interactions of the internal flows and the rotating components of the engine.

Figure 9 represents a situation where the discrete frequency tones are strong compared to the broad band noise. Such a condition may exist for

turbojet engines operating at partial power conditions or for turbofan engines which incorporate large rotating machinery components. In the latter case, these tones may be observable both in front of and to the rear of the engine. The time history of the noise pressures for such a noise condition has the gross features of an amplitude modulated sine wave as indicated in the top sketch of figure 9.

For the condition where the broad band noise is the dominant component, the data of figure 10 will apply. The broad band noise dominates for engines having high exit velocities or which have been modified to reduce the pure tone components. The noise pressure time histories in such cases have the appearance of a random signal as indicated in the top sketch of figure 10.

NOISE RADIATION PATTERNS

Noise radiation patterns for the three types of noise sources considered in this paper are illustrated schematically in figure 11. The reciprocating engine exhaust which has the main features of a simple acoustic source has essentially a nondirectional radiation pattern. The propeller which can be represented by an area distribution of dipole acoustic sources radiates the maximum noise generally in the direction of the plane of the propeller and slightly behind it as indicated by the middle sketch. The jet exhaust noise which arises because of a shearing action of the flows and which has the main features of a volume of quadrupole acoustic sources has maximum noise radiation to the rear at approximately 40° from the thrust axis.

At high speeds, the directional patterns of these sources will differ somewhat from those of the static condition. For the purpose of this paper, however, the forward speed effects will generally be small except in the case of the propeller as suggested by figure 12.

The sketches of figure 12 represent the sound pressure level distributions as a function of distance along the ground underneath a rotating propeller. The left hand sketch represents the propeller operating in such a way that its plane of rotation is perpendicular to the ground, the maximum value being behind the plane of rotation. For the static case where the propeller plane is parallel to the ground, and in a static or hovering configuration, a double peaked symmetrical sound pressure level distribution pattern is observed.

For the case of forward speed of the propeller as in a transition maneuver, the asymmetrical pattern of the dashed line is obtained from theoretical analyses of D. L. Lansing and J. A. Drischler, Jr., of NASA Langley Research Center. In this case, the forward radiation lobe is strengthened to the

extent that higher noise levels over a greater distance are observed on the ground. This characteristic distortion of the pattern would be accentuated at increased forward speeds.

PREDICTION METHODS

The methods available for predicting the noise from the various sources considered in this paper are indicated in figure 13. For the case of the reciprocating engine, reliance is placed entirely on experimental noise data. Although more sophisticated prediction methods may eventually be available, their development is hindered by the nonlinear acoustic propagation situations existing within the collector manifolds and exhaust pipes. In the case of the jet exhaust a large amount of experimental data have been collected and some theoretical work is available which indicates behavior trends of the data. Thus, empirical methods are available for noise prediction based on a knowledge of the engine operating conditions. In the case of propellers some theoretical methods are available for noise prediction in addition to experimental and empirical procedures. Theoretical methods are at present known to be useful only for some special cases and are not generally adequate for all prediction purposes.

NOISE SOURCES

- PROPELLERS
- RECIPROCATING ENGINES
- GAS TURBINE ENGINES
  - TURBOJET
  - TURBOFAN

Figure No. 1

SOURCE CHARACTERISTICS

- NOISE LEVELS
- FREQUENCY SPECTRA
- PRESSURE TIME HISTORIES
- RADIATION PATTERNS
- DURATION

Figure No. 2

ANNOYANCE REACTION

(BASED ON 1/3 OCTAVE BANDS)

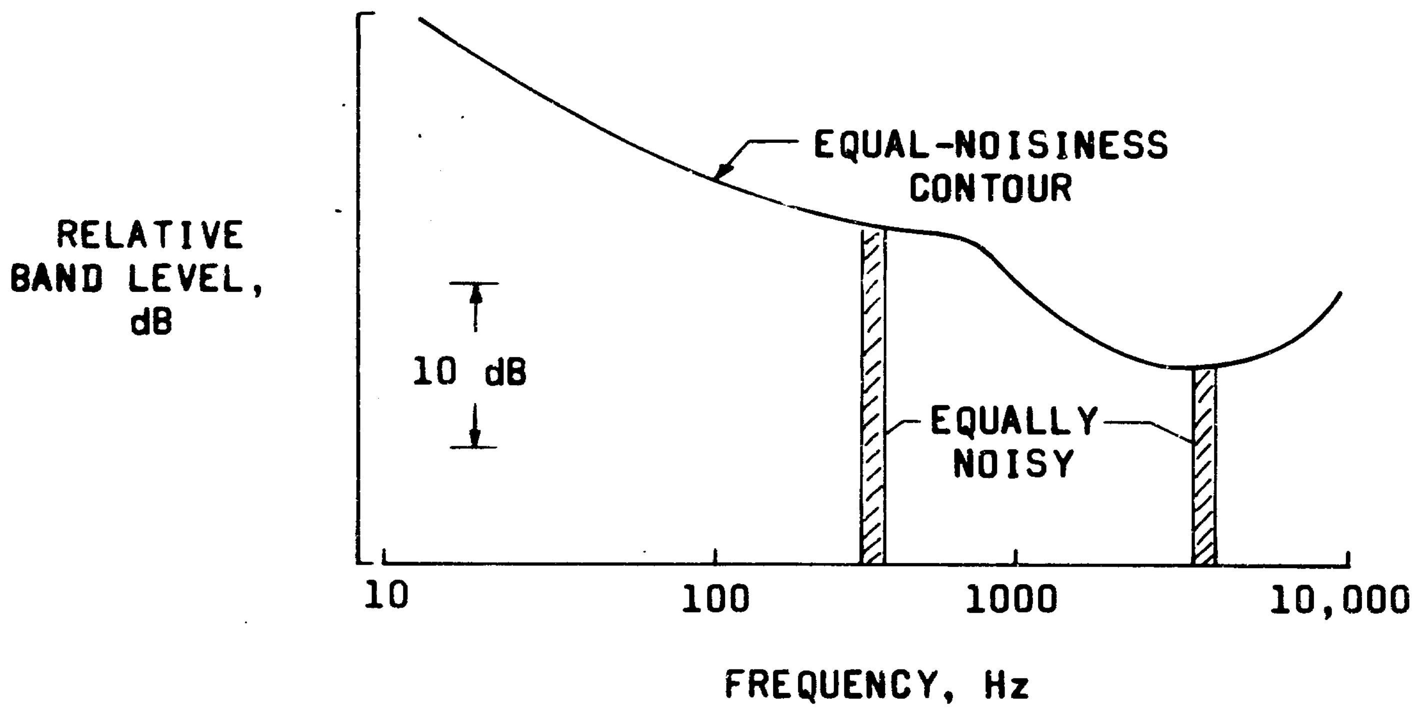

Figure No. 3

ATMOSPHERIC LOSSES

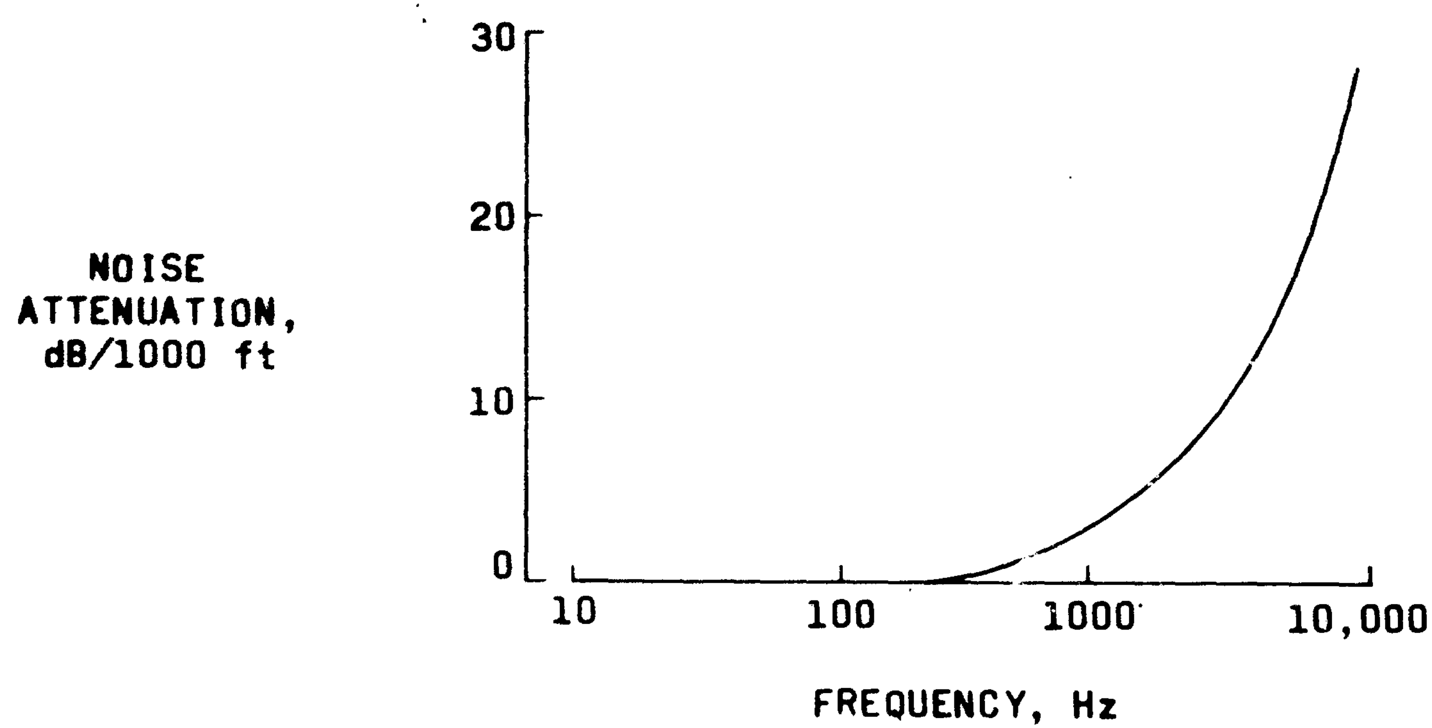

Figure No. 4

TYPE OF SPECTRA

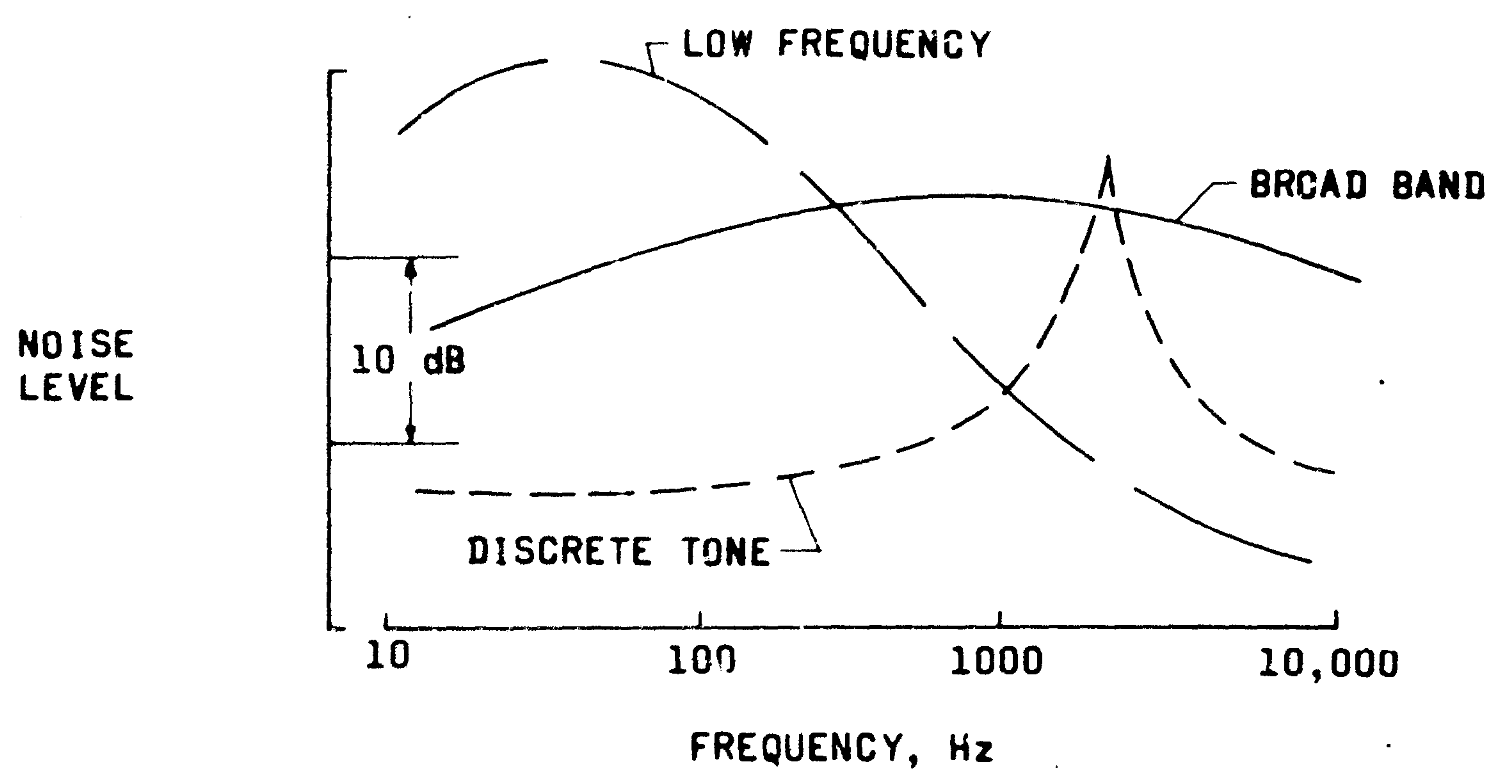

Figure No. 5

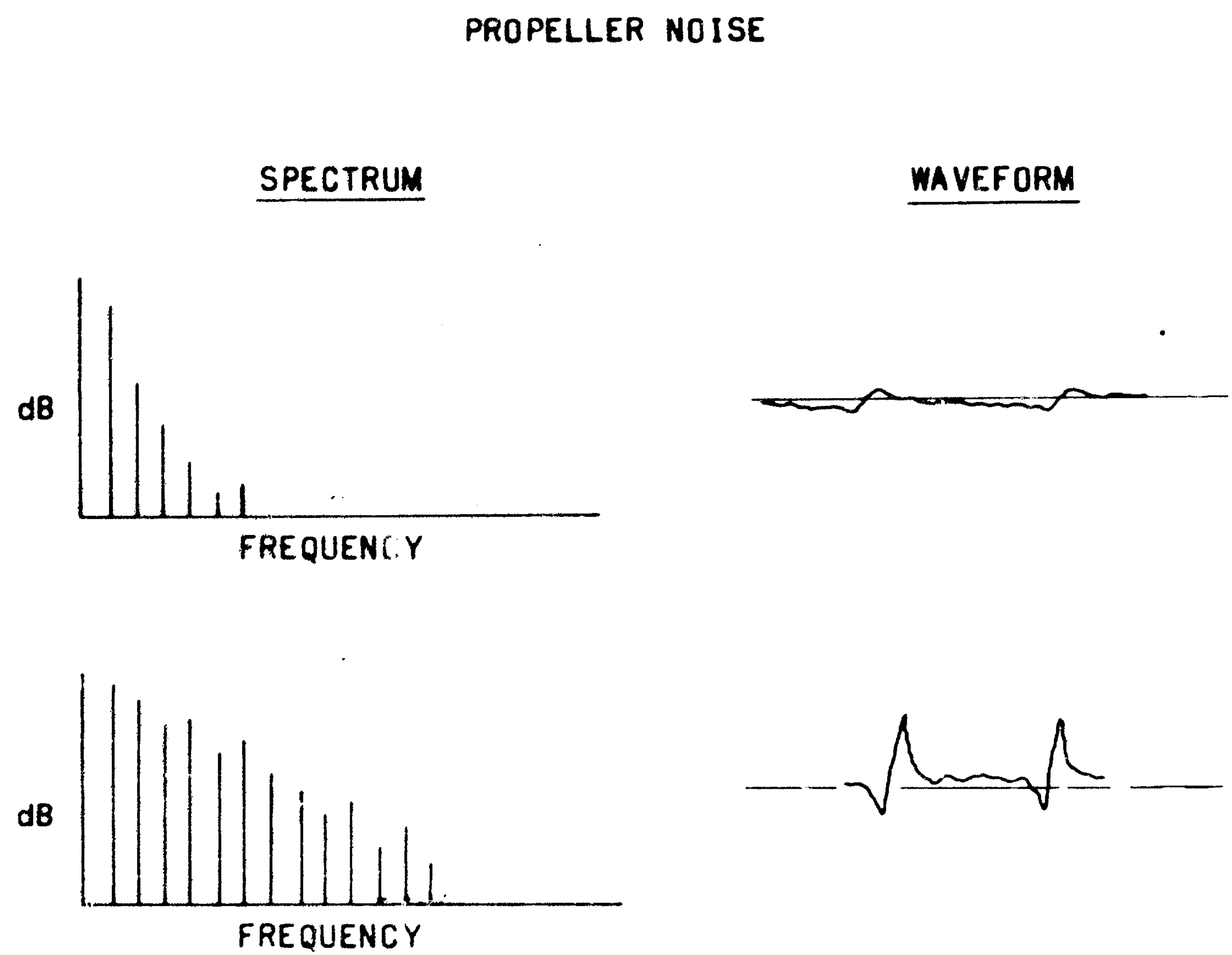
PROPELLER NOISE
SPECTRUM
WAVEFORM
dB
FREQUENCY
dB
FREQUENCY

Figure No. 6

GAS TURBINE - PROPELLER

(3 Hz BANDWIDTH)

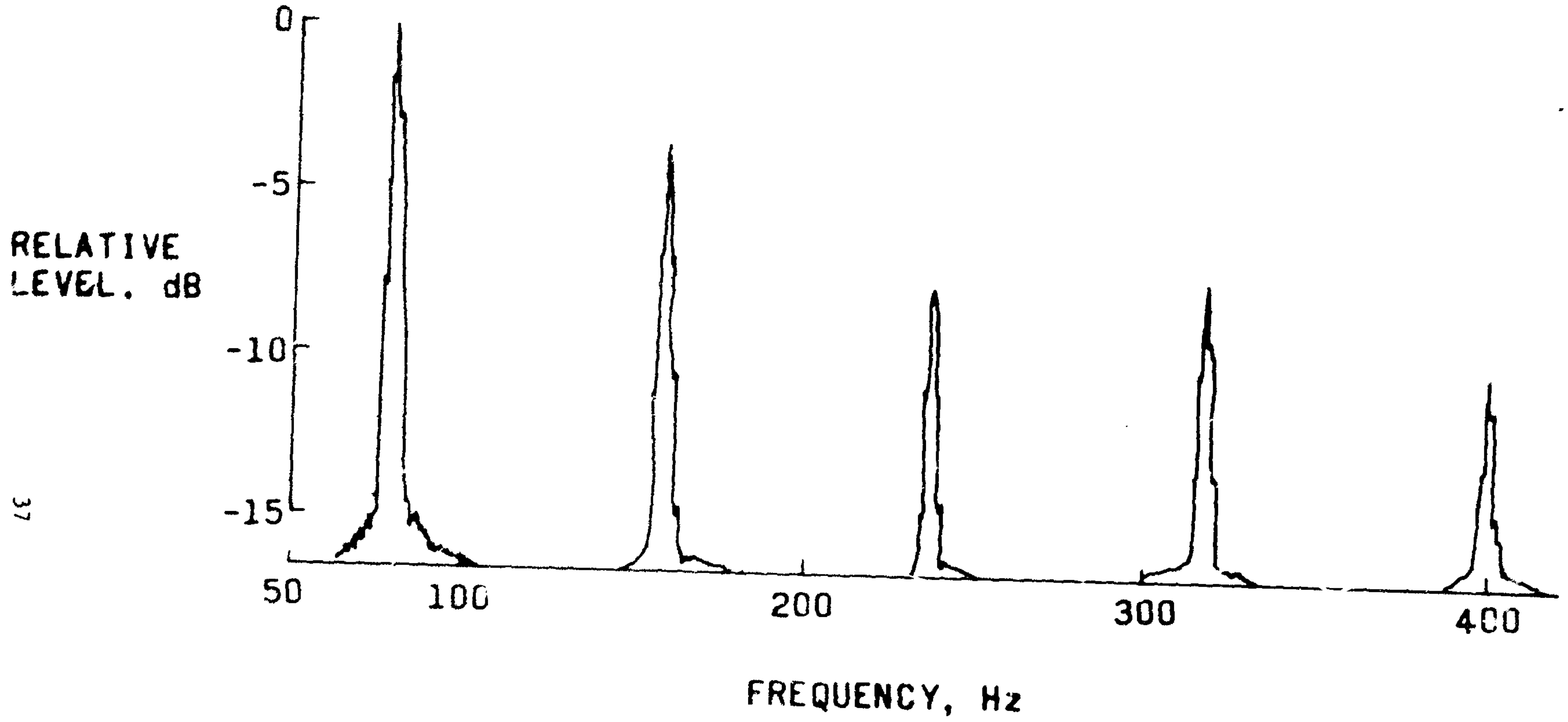

Figure No. 7

RECIPROCATING ENGINE-PROPELLER

(3 Hz BANDWIDTH)

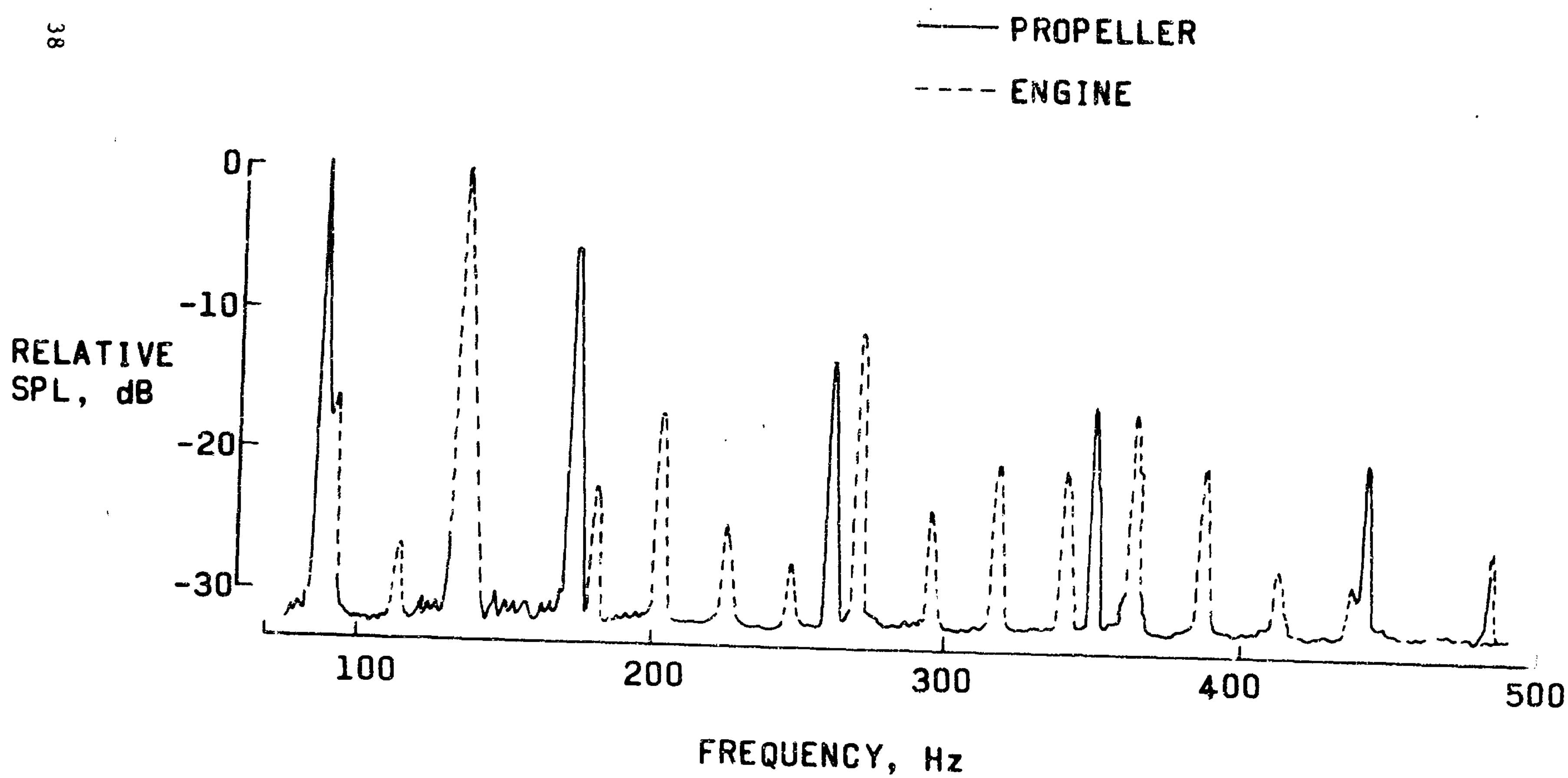

Figure No. 8

TURBOFAN NOISE

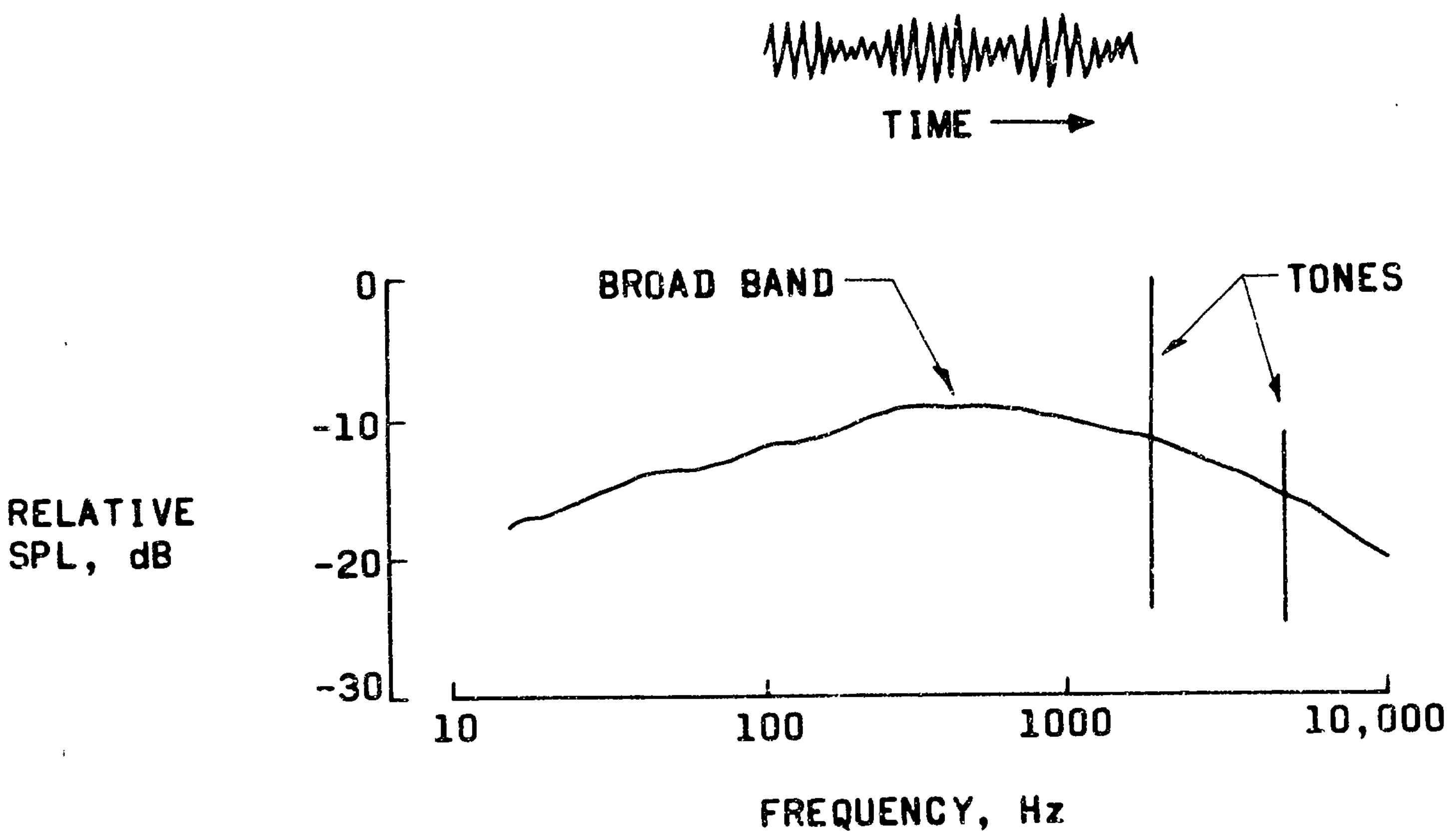

Figure No. 9

TURBOJET NOISE

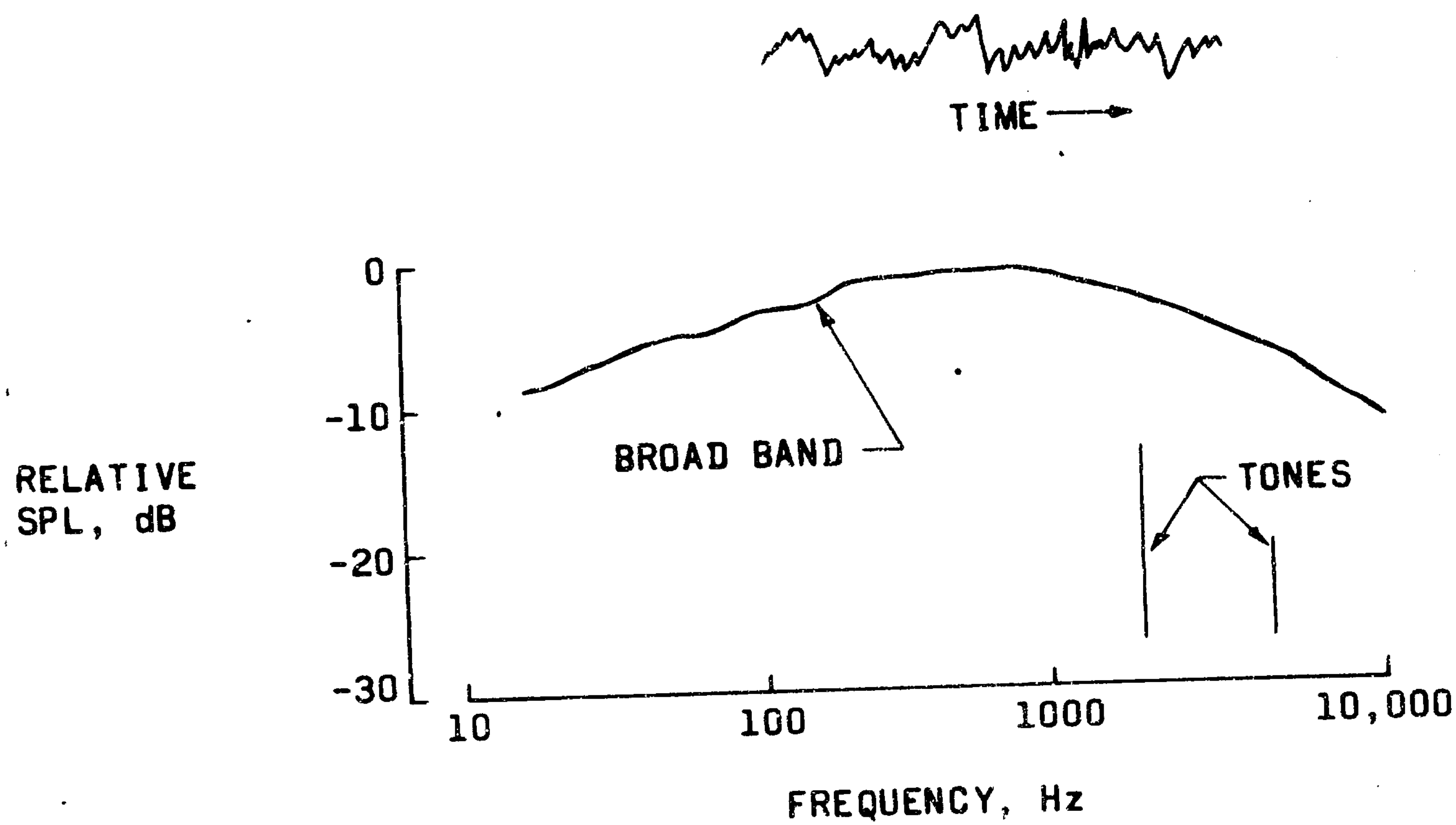

Figure No. 10

NOISE RADIATION PATTERNS

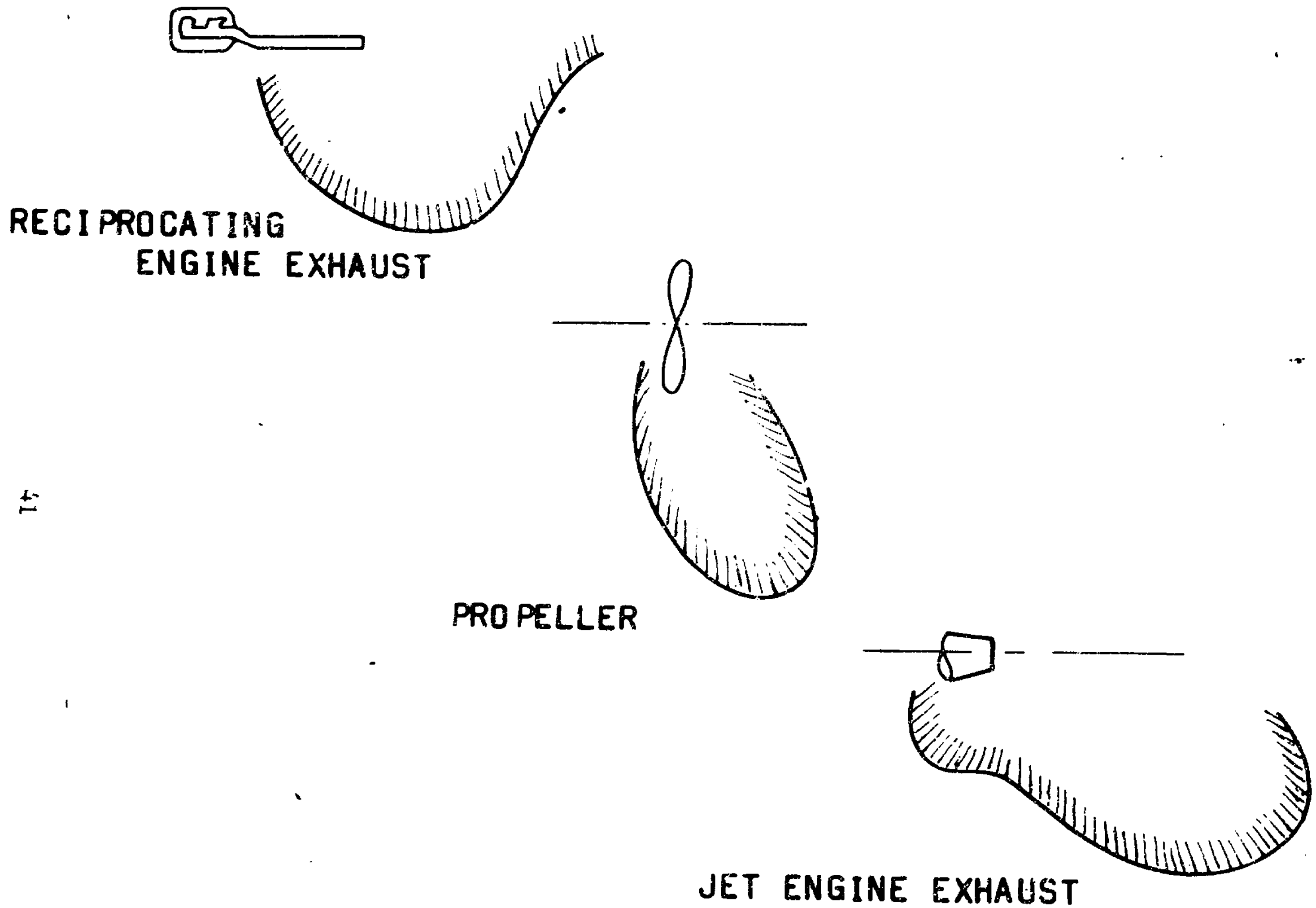

Figure No. 11

PROPELLER NOISE RADIATION PATTERNS

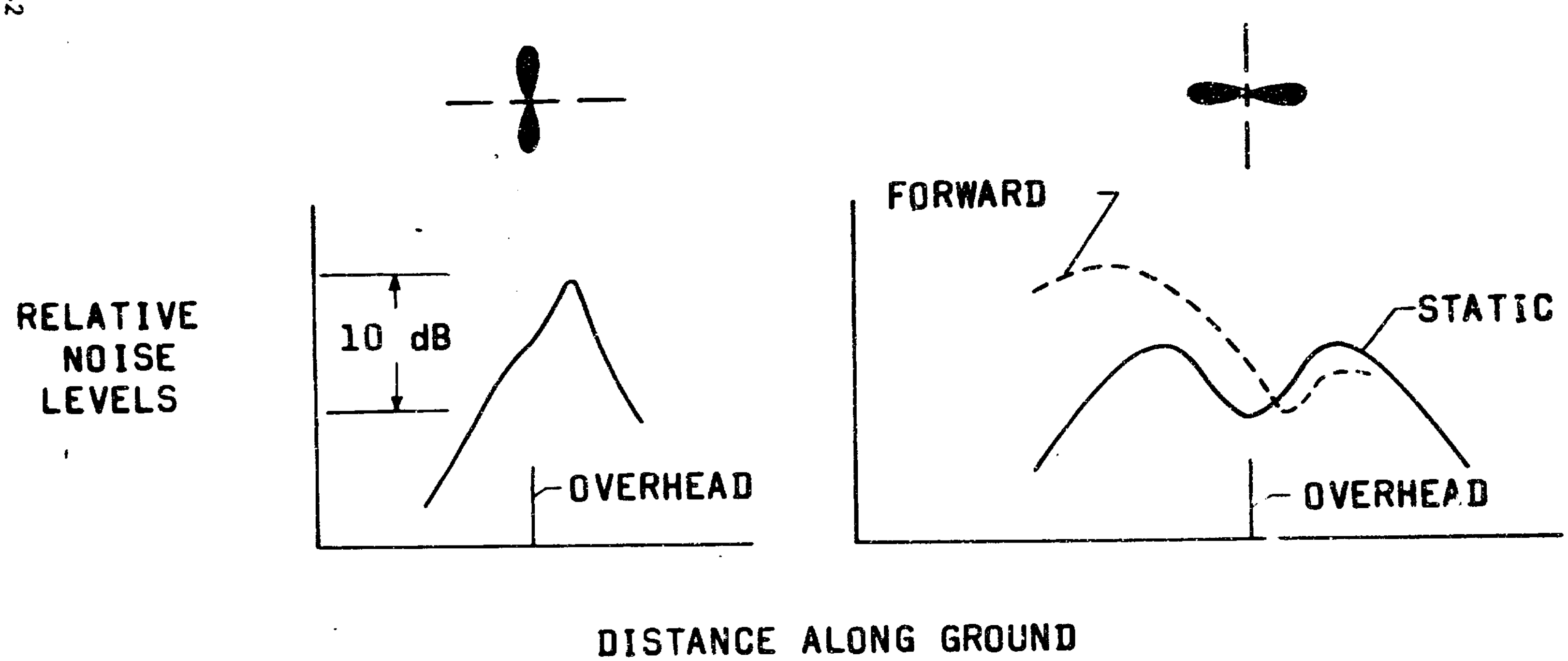

Figure No. 12

NOISE PREDICTION METHODS

SOURCE	AVAILABLE PROCEDURES		
	EXPERIMENTAL	EMPIRICAL	THEORETICAL
RECIPROCATING ENGINE	✓		
JET EXHAUST	✓	✓	
PROPELLERS AND FANS	✓	✓	✓

Figure No. 13

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CHARACTERISTICS OF NOISE GENERATED BY
DUCTED PROPELLERS AND FANS

by

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Delivered at
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Aircraft Noise Certification

J ..uary 30, 1969

Federal Aviation Administration
Washington, D. C.

CHARACTERISTICS OF NOISE GENERATED BY DUCTED PROPELLERS AND FANS

In a previous paper, Mr. Deckert has shown typical STOL aircraft and has established that with existing power plants they will be noisy or costly to operate or both. Before power plant noise is reduced, it is first necessary to understand how the noise is generated. Figure No. 1 is a list of noise sources. One basic source is the rotational noise caused by the pressure field received by an observer stationary with respect to a rotor. This noise appears at the blade passing frequency and harmonics of the blade passing frequency. Another noise source is the vortex, or viscous noise. This noise occurs over a broad frequency range. The third basic noise source is jet mixing, and is caused by the shearing action of two fluids at different airspeeds. When propulsion components are added together, interactions between the components can cause noise. Especially well known is the interaction of a rotor and an adjacent stator. Impulsive noise comes from still another source. Rotor blade slap is a well known example of this. Impulsive noise comes from operation of the propulsion system in such a manner that the operating environment has time variant features. Before moving on, a point should be made about jet mixing noise. It has been fashionable in the past to equate noise and disk loading. Low disk loading automatically meant low noise. Actually, disk loading defines jet velocity only. Figure No. 2 shows jet mixing noise versus wake velocity. Spotted on this curve are rotary wing, propeller, and lift fan data from Mr. Deckert's paper. Even though the level of the wake mixing noise can be debated at the lower velocity end of the curve, the noise is far below other power plant noise sources in the types of power plants to be considered here. Therefore, jet mixing will not be discussed as a noise source for this paper.

Before proceeding further, it is necessary to define ducted propellers and fans. As shown in Figure No. 3, a ducted propeller has a very low pressure ratio which means stators are not required and cruise speeds will be relatively low. On the other hand, ducted fans may have pressure ratios to 1.5. With this pressure ratio, stators are required. Cruise speeds with these types of fans can approach .9 Mach number. Figure No. 4 is a sketch of a typical ducted propeller. The propeller will typically have few blades and centerbody support struts. The primary noise source would be expected to be rotational noise. The ducted fan, sketched in Figure No. 5, usually has the rotor and stator close together to minimize volume and weight. This means that rotor-stator interaction can be the primary noise source. The noise is caused by time variant pressure fields that originate from operation in the wake and potential field of another component.

Some of the characteristics of ducted propeller and fan noise are shown in the following figures. Figure No. 6 shows sound pressure level as a function of frequency for a 1.1 pressure ratio fan. The fan rotor harmonics are well defined. This fan was driven by a turbojet engine and the noise at the blade passing frequency of the engine compressor is also well defined.

This noise is a combination of rotational noise and rotor-stator interaction noise. If these sources could be eliminated the sound pressure level would drop 10 to 15 db. The remaining noise is vortex and jet mixing noise. The directivity of noise from two ducted propellers and a fan is shown in Figure No. 7. For the two-bladed propeller, noise peaks about 50° from the inlet axis and again 120° from the inlet axis. For the three-bladed propeller, which happens to be a full-scale X-22 propeller, the sound pressure level peaks as with the smaller propeller. The curve labeled 1.1 pressure ratio is for the same fan that provided the previously discussed spectrum. It shows directivity similar to the other fans, except that there is a small peak on the fan axis. In general, the directivity of the three units is very similar in spite of their diverse geometry. Perhaps the extreme case in fan designs is the lift fan (Figure No. 8). Since this fan is used only for direct lifting, it must be easily stowable. Therefore, by definition, a lift fan is short axially, and noise from close rotor-stator spacing is likely to be strong.

The lift fan, because of its small volume and length, will try the ingenuity of noise reduction technologists. Up until this time there has been no comment on the fan drive system. The only full-scale fans available today are tip turbine fans. Figure No. 9 shows how these fans operate. The exhaust gas from the engine is channeled to the scroll that distributes the gas circumferentially around the fan then exhausts the gas through a nozzle into the tip turbine which is an integral part of the fan rotor. A great deal of the energy of the exhaust is absorbed by the tip turbine so that jet mixing noise is low. For fans now flying in the XV-5, there are seven turbine blades for each fan blade. This puts the turbine blade passing frequency near the upper limit of audibility, thus turbine noise is low and the main noise source external to the fan is the engine compressor. Of course these external noise sources must be carefully considered in propulsion system noise analyses. Measured directivity of two lift fans, one with outlet guide vanes and one with inlet guide vanes, is shown in Figure No. 10. The axes are oriented in the same manner as the earlier directivity plot. The directivity is very similar to that of the fans with longer shrouds. Thus it would seem that directivity patterns, in terms of sound pressure level, are likely to be similar for any ducted propeller or fan.

Few measurements are available to verify noise predictions of complete STOL airplanes. Some measurements are available for a large-scale lift fan model (Figure No. 11). This model had six three-foot diameter lift fans that were driven by two J-85 engines. The model was nine feet above the ground. The engine inlets were located above the fuselage so that compressor noise probably was not a large contributor. One quarter of the exhaust gas from each engine was exhausted near the tail of the model

and probably contributed to noise in the rear quadrant. Even so the shape of the footprint is remarkably similar to that shown earlier by Mr. Deckert, for a similar propulsion system. This again tends to validate methods of predicting the noise directivity of ducted fans.

The main concern of this paper will now shift from ducted fans to rotorcraft. Although rotorcraft are generally considered to be VTOL aircraft, they can operate in a STOL mode and landing and takeoff air maneuvers may be similar to winged STOL aircraft. One type of rotorcraft that can be operated STOL is shown in Figure No. 12. Here the rotor normally provides vertical lift then tilts 90° to provide cruise thrust. Operation at mid tilt angles will allow take-off at weights much heavier than the VTOL weight. Another possible STOL rotorcraft is shown in Figure No. 13. Here the rotor can be stopped, folded, and retracted into the fuselage leaving a reasonably clean cruise configuration. With a proper power management system, this type of aircraft should also have STOL capability.

Rotary wing noise sources are listed in Figure No. 14. Rotational and vortex noise has been discussed earlier. Another major source of noise is blade slap. This can be caused by shock waves on the advancing blade of a rotor or by stall on the retreating blade of the rotor. Cutting of the tip vortex from one blade by the blade of another also produces blade slap. Figure No. 15 shows the noise spectrum of a typical hovering helicopter. The main rotor harmonics show the rotational noise as the primary noise source with the tail rotor rotational noise not much less. Vortex noise is quite low. Figure No. 16 shows noise spectra at forward speed.

Rotor advance ratio is nearly constant for the two traces, but the advancing tip Mach number varies. At .8 tip Mach number, the spectrum is similar to the hover noise spectrum. However, at .9 tip Mach number, a new noise source between 70 and 170 hertz has become the primary noise source. The effect of advancing blade tip Mach number on overall sound pressure level is shown in Figure No. 17. The advancing tip Mach number is a very important parameter in the noise generated by rotary wing aircraft in cruise flight. Figure No. 18 is an artist's attempt to depict the interference between the rotor blade and the tip vortex. When the aircraft is accelerating and climbing, it moves away from the helix made up of the tip vortex. Conditions are similar for autorotating descents. The problem occurs when the aircraft is flying at a low descent rate or with the rotor unloaded. The rotor then moves through its own tip vortex system.

This concludes the discussion of noise generation. Subsequent papers will take up the question of reducing noise generated by these sources.

SOURCES OF NOISE

BASIC:

- ROTATIONAL
- VORTEX
- JET MIXING

ROTOR-STATOR INTERACTION

IMPULSIVE:

- STALLED FLOW
- ROTOR BLADE SLAP

Figure No. 1

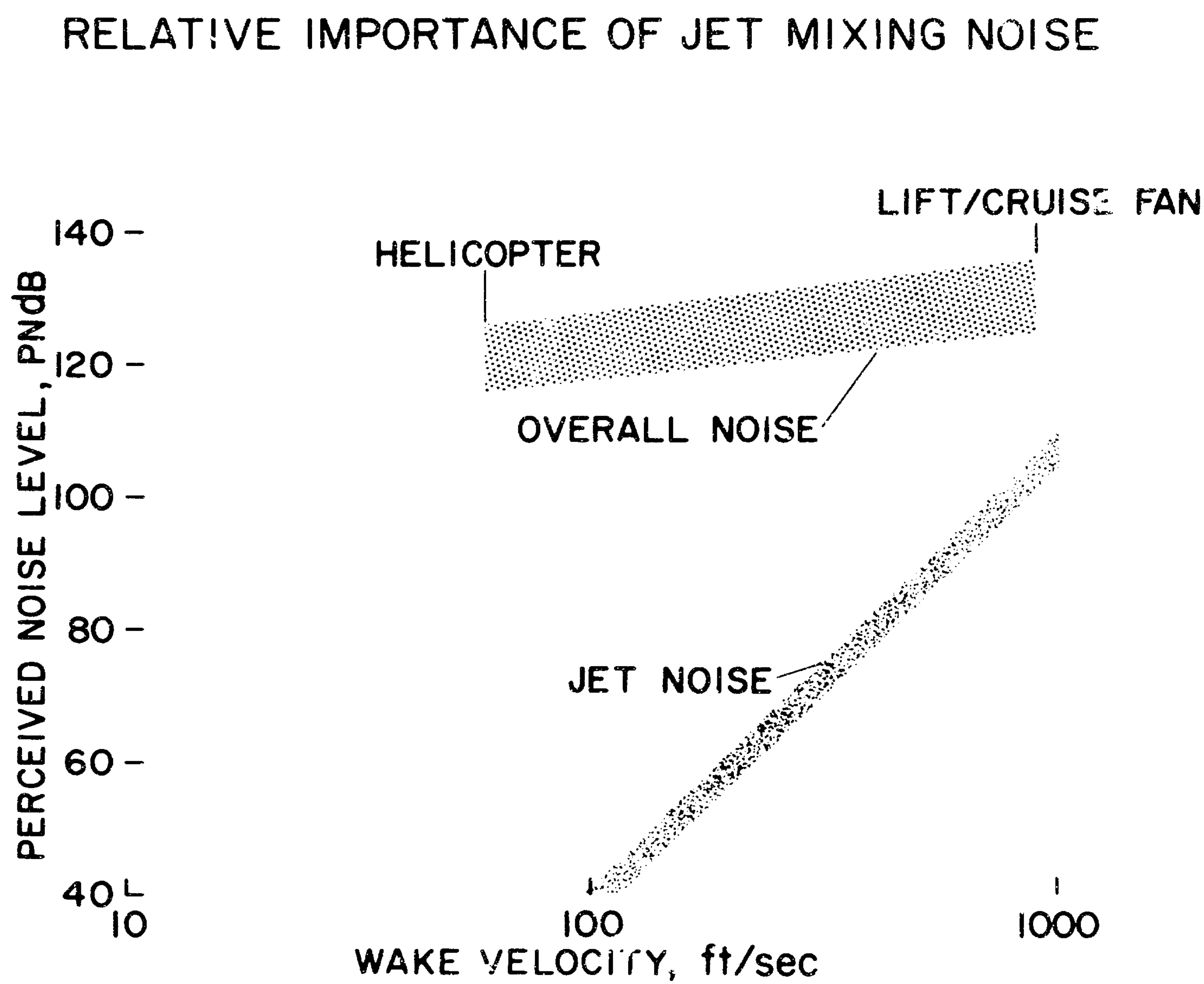

RELATIVE IMPORTANCE OF JET MIXING NOISE
LIFT/CRUISE FAN
HELICOPTER
OVERALL NOISE
JET NOISE
PERCEIVED NOISE LEVEL, PNdB
140
120
100
80
60
40
10
100
1000
WAKE VELOCITY, ft/sec

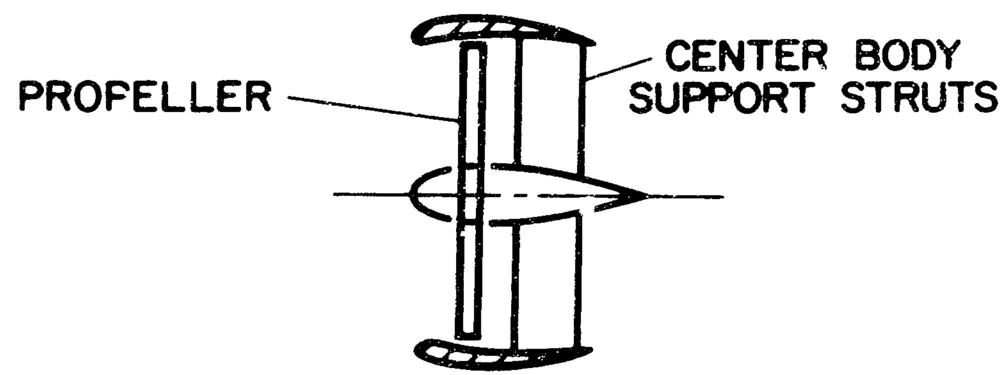
Figure No. 2

DUCTED PROPELLERS AND FANS

- DUCTED PROPELLERS
  - PRESSURE RATIO 1.01 TO 1.03
  - STATORS NOT REQUIRED
  - RELATIVELY LOW CRUISE SPEED
- DUCTED FANS
  - PRESSURE RATIO 1.03 TO 1.5
  - STATORS ARE REQUIRED
  - INCLUDES LIFT/CRUISE FANS
  - CRUISE SPEED TO .9 MACH NUMBER

Figure No. 3

TYPICAL DUCTED PROPELLER

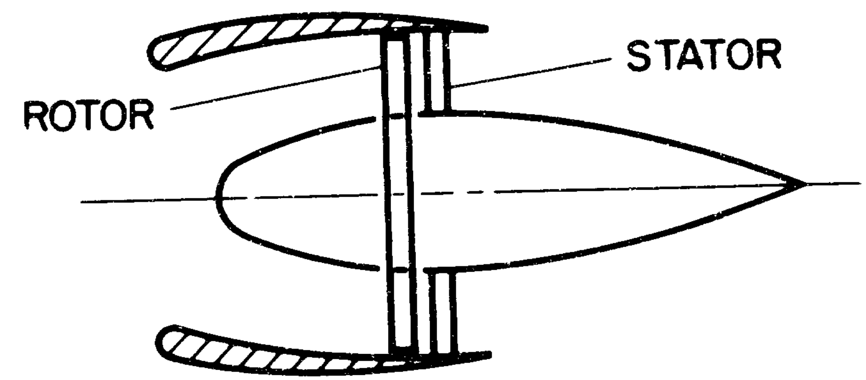


PRIMARY NOISE SOURCES

- ROTATIONAL NOISE
- VORTEX NOISE

Figure No. 4

TYPICAL DUCTED FAN



PRIMARY NOISE SOURCES

- ROTOR - STATOR INTERACTION
- ROTATIONAL

Figure No. 5

SPECTRUM OF NOISE FROM A LIFT-CRUISE FAN

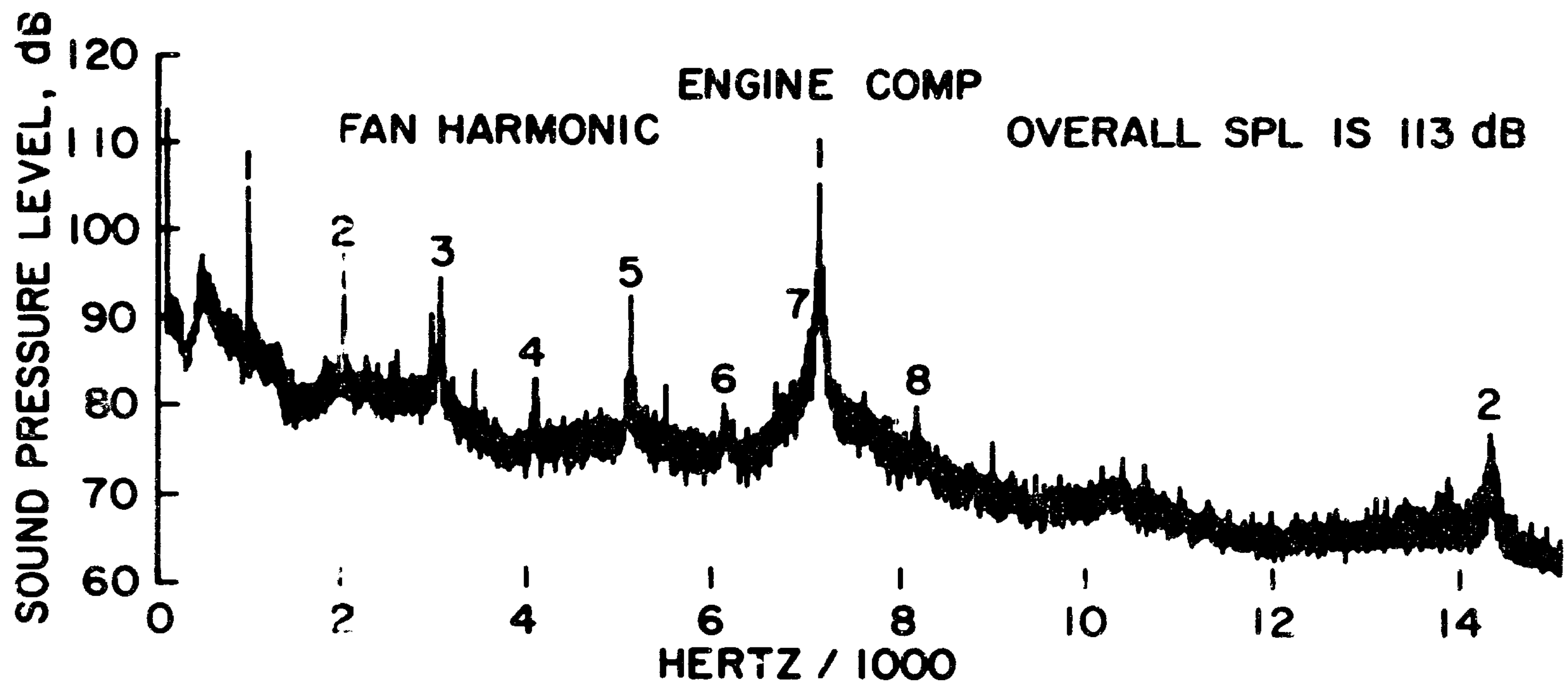


Figure No. 6

Hiccey

NOISE DIRECTIVITY FOR SEVERAL DUCTED FANS

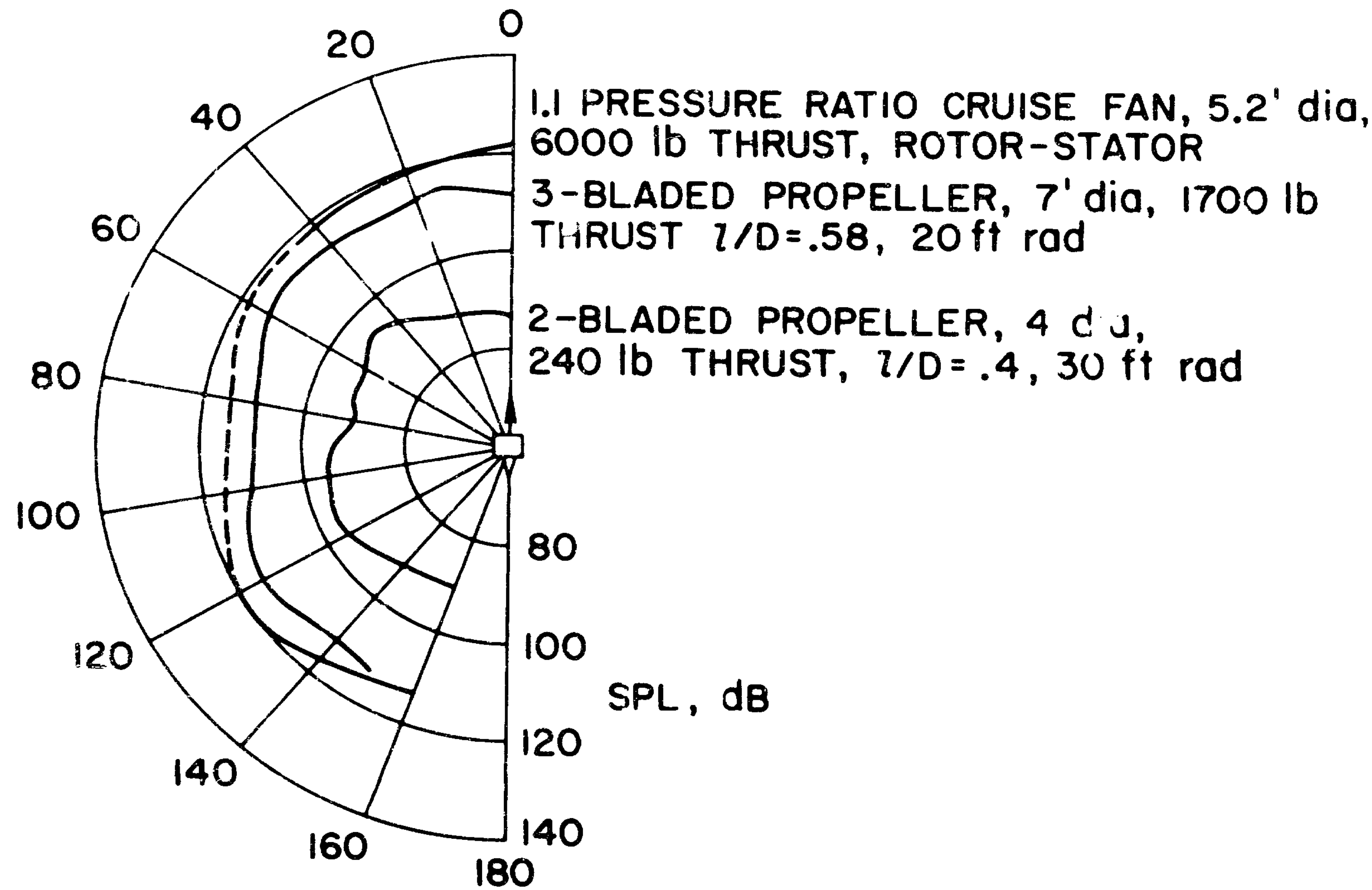
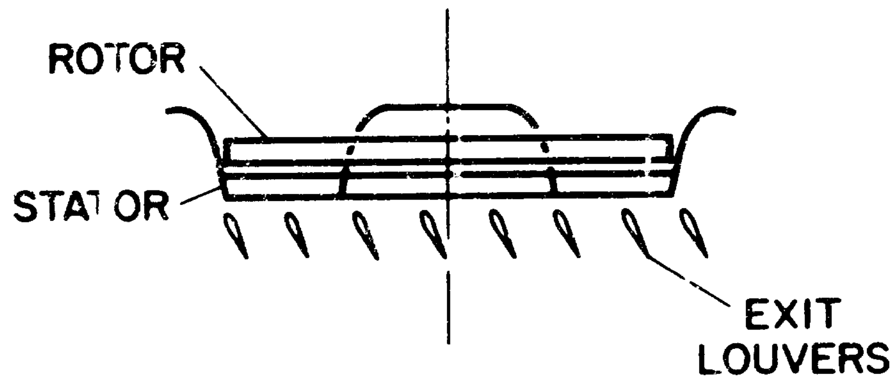


Figure No. 7

TYPICAL LIFT FAN



RIMARY NOISE SOURCES

- ROTOR - STATOR INTERACTION
- ROTATIONAL

Fig re No. 8

HICKEY

TYPICAL TIP-TURBINE DRIVEN LIFT FAN

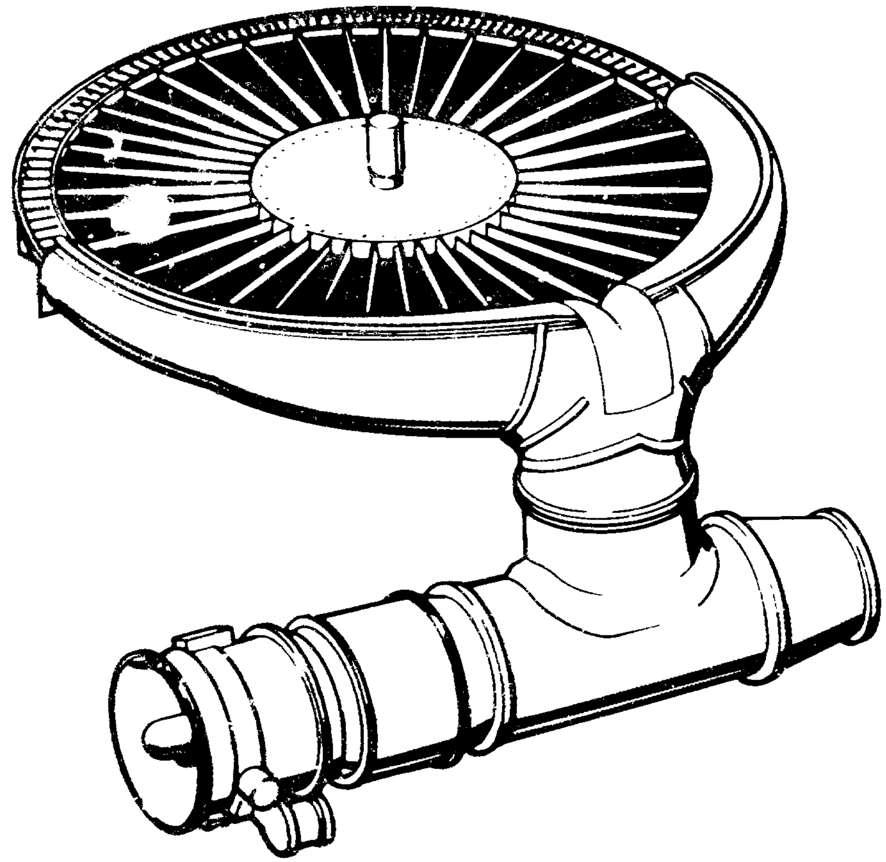


Figure No. 9

NOISE DIRECTIVITY FOR LIFT FANS

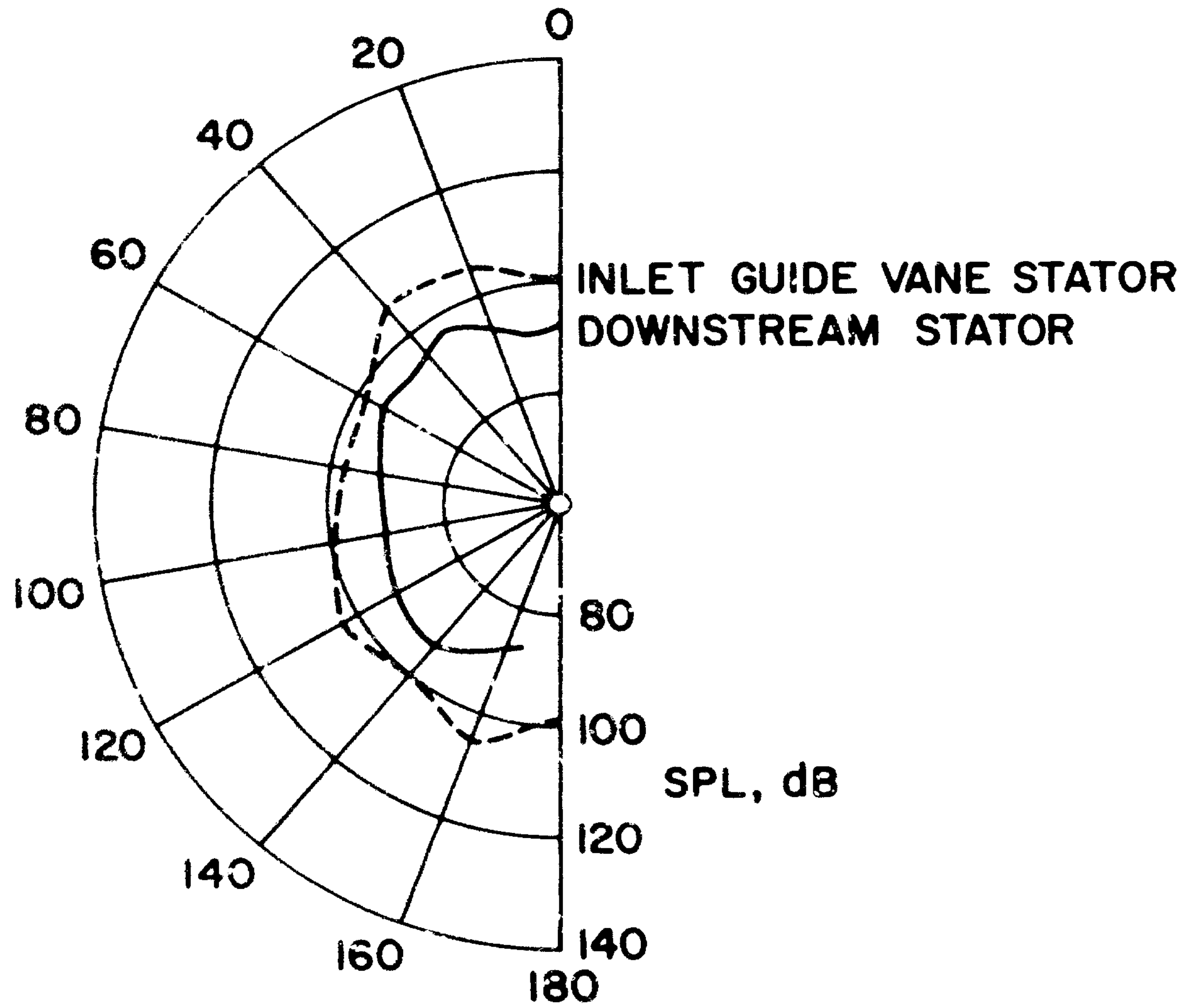


Figure No. 10

NOISE DIRECTIVITY OF LARGE SCALE LIFT FAN MODEL

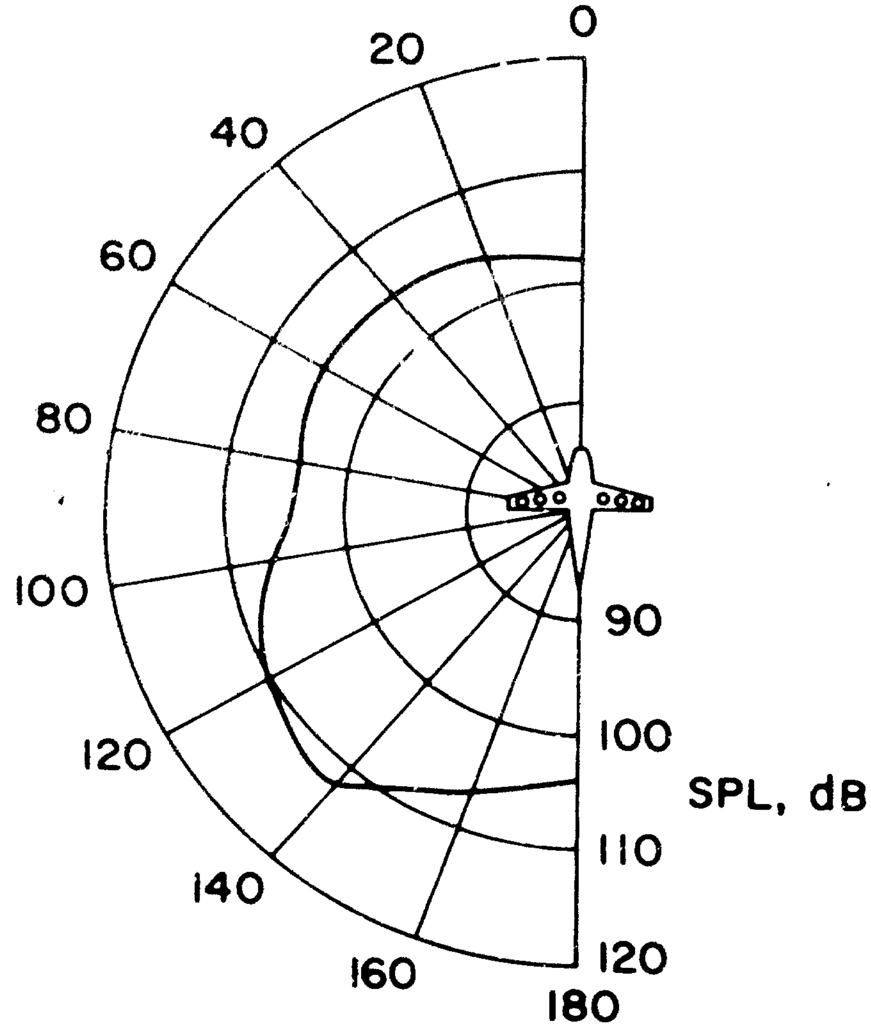


Figure No. 11

TILT ROTOR AIRCRAFT

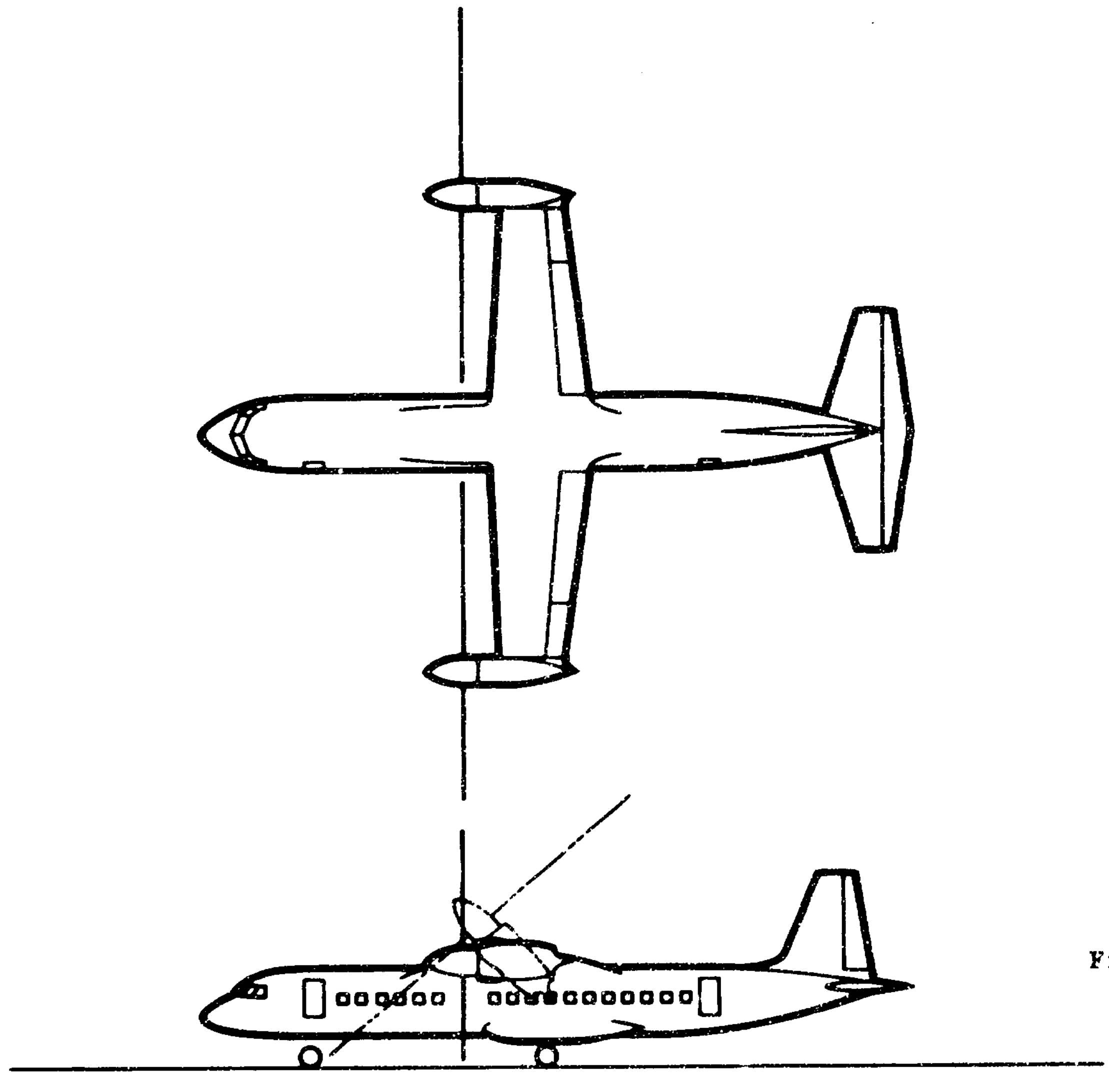


Figure No. 12

60-PASSENGER STOPPED ROTOR AIRCRAFT

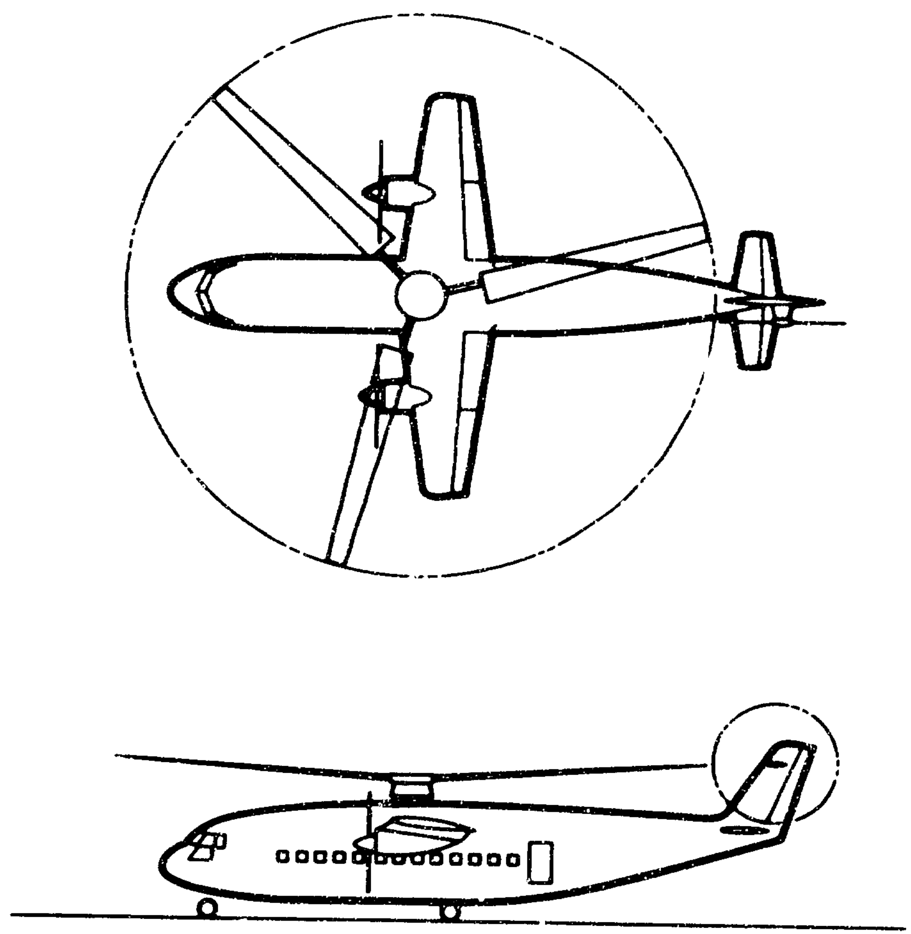


Figure No. 13

HELICOPTER ROTOR NOISE SOURCES

- ROTATING PRESSURE FIELD
  (ROTATIONAL NOISE)
- VORTEX NOISE
- BLADE SLAP
  - COMPRESSIBILITY
  - RETREATING BLADE STALL
  - VORTEX INTERACTION

Figure No. 14

TYPICAL HELICOPTER NOISE SPECTRUM

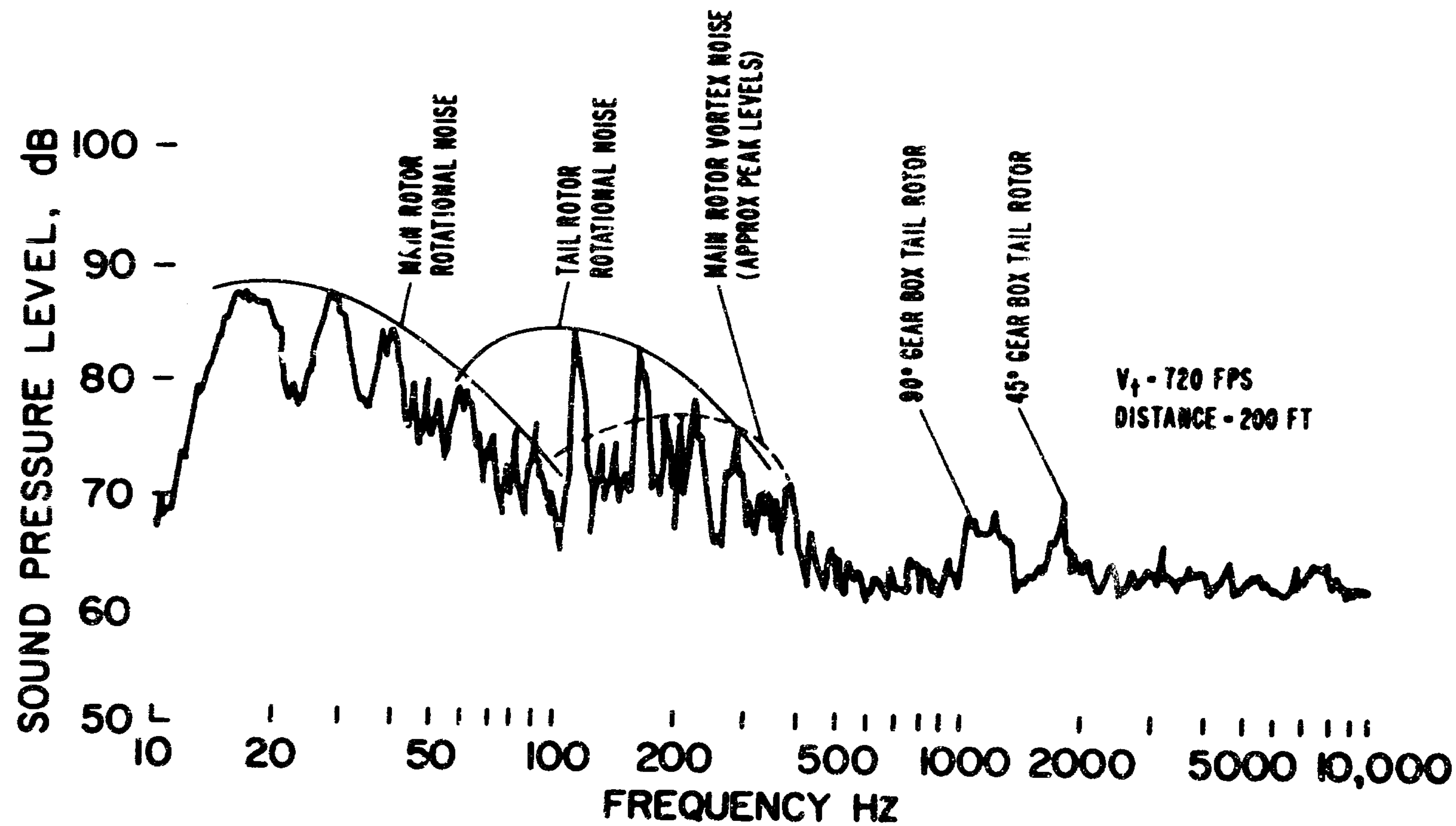


Figure No. 15

EFFECT OF ADVANCING TIP MACH NUMBER OF HELICOPTER NOISE SPECTRUM.

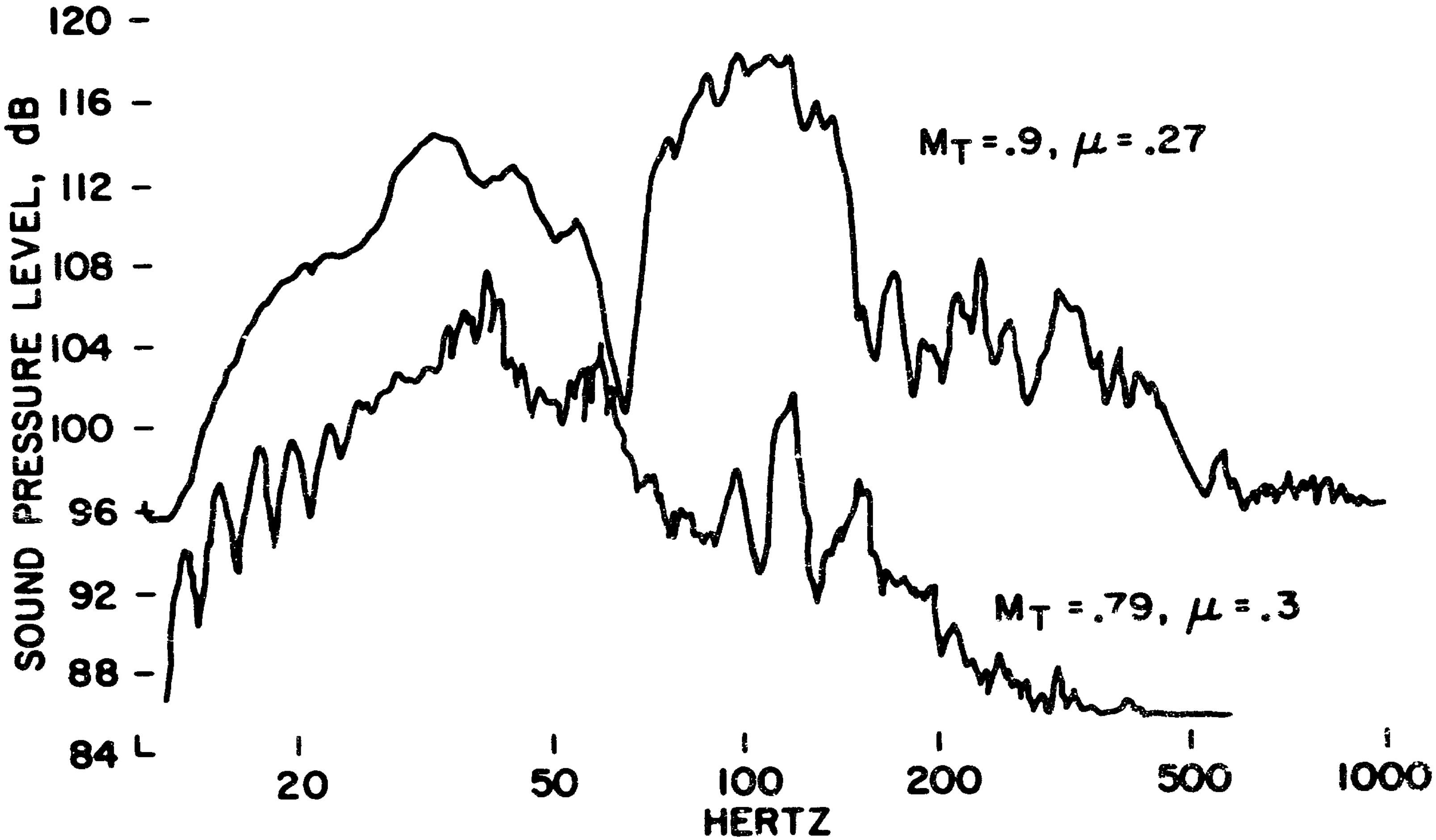


Figure No. 16

EFFECT OF ADVANCING TIP MACH NUMBER

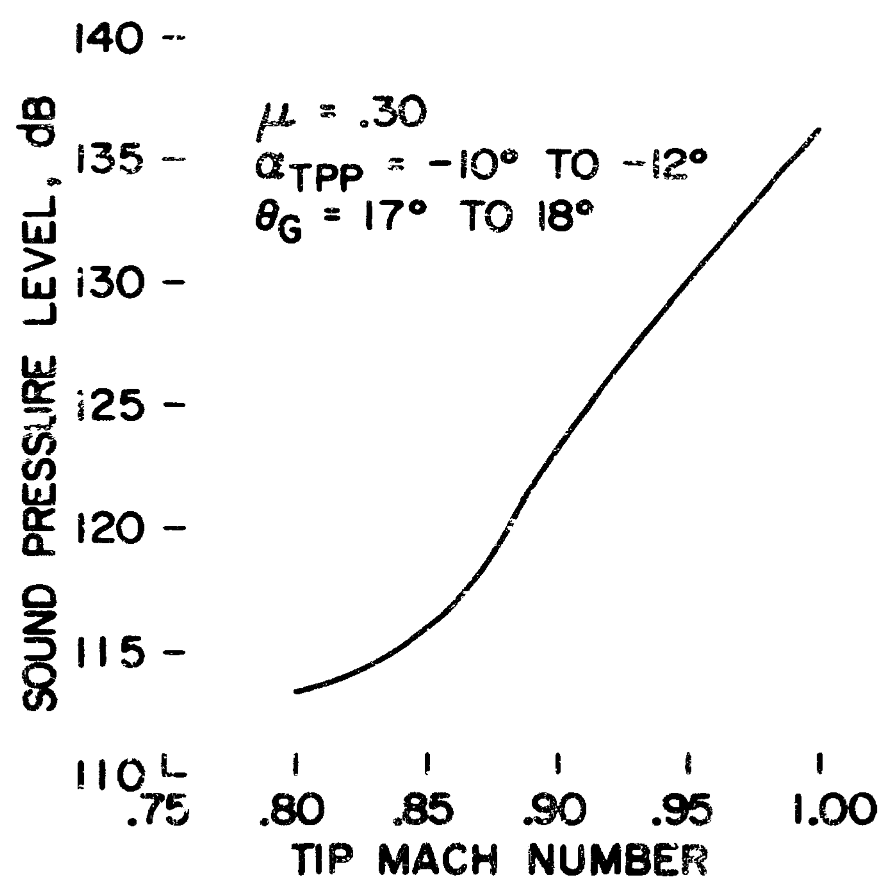


Figure No. 17

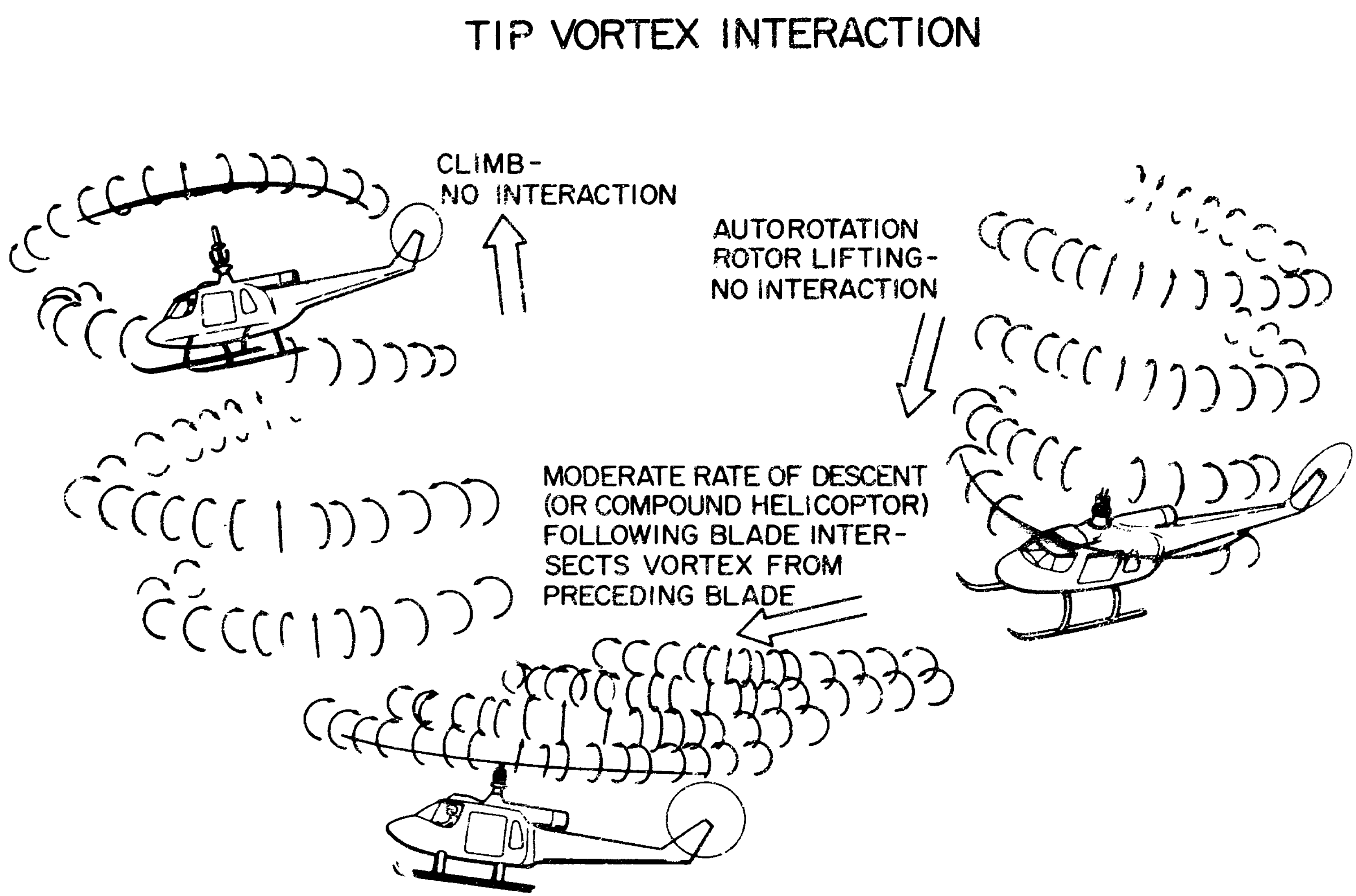

TIP VORTEX INTERACTION
CLIMB-
NO INTERACTION
AUTOROTATION
ROTOR LIFTING-
NO INTERACTION
MODERATE RATE OF DESCENT
(OR COMPOUND HELICOPTOR)
FOLLOWING BLADE INTER-
SECTS VORTEX FROM
PRECEDING BLADE

Figure No. 18

STOL NOISE ABATEMENT OPERATIONAL CONSIDERATIONS

by

Alder P. Betti
Paul D. Wilburn
Flight Standards Service

Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

STOL NOISE ABATEMENT OPERATIONAL CONSIDERATIONS

Aviation noise problems are not confined to any one locale, nor to any particular type of aircraft. Pick up any aviation periodical today and one need not look too hard to find articles on noise. Some states have already scheduled public hearings on this problem, and the Federal Government is presently involved in drafting regulations to control and alleviate aircraft noise. In the Los Angeles area alone, more than one-half billion dollars are being litigated, and we can assume that similar law suits are pending throughout the United States. I'm sure much of this information is not entirely new to you, but it does point out the importance attached to the aircraft noise problem.

We, of Flight Standards, are not only interested in the type and operational certification of STOL aircraft, but are vitally concerned with the associated noise created by them.

On July 1, 1968, the Federal Aviation Administration issued tentative airworthiness standards for vertical/powered lift transport category aircraft. The issuance has become commonly known as the "Yellow Book." The Aerospace Industries Association contributed substantially to this publication. It should be noted, however, that there are no aircraft noise considerations in this publication. Accordingly, anyone contemplating certification of a STOL aircraft should also refer to the applicable aircraft noise regulations when issued.

There are varied views as to how operational considerations can best be utilized to alleviate noise. We believe that operational considerations as a means of abating noise should only be implemented as an adjunct to the more meaningful ways of suppressing noise; i.e., by better aircraft and/or engine design. This does not mean that we will not establish noise abatement procedures at selected airports if the need dictates and the environment permits.

(1) Today, operational noise abatement procedures apply to all aircraft, including STOL. These procedures which have been established and implemented require that aircraft fly selected approach and departure routes to and from an airport in order to minimize noise complaints.

(2) In addition to following these specific routes, aircraft are requested to climb and descend to desired altitudes as soon as practical in order to lessen the noise exposure time. Some procedures require that an aircraft remain at a given altitude prior to beginning a descent in order to alleviate noise complaints.

(3) Another means of abating noise is that of requiring pilots to reduce power prior to reaching these critical noise areas.

(4) Still another procedure calls for execution of a turn as soon as practical after departing a runway.

All of these procedures are presently being followed in an effort to minimize objectionable noise areas. Of prime concern, prior to the establishment and implementation of any noise abatement procedure is that these procedures must be thoroughly examined to assure that safety is not compromised.

Since STOL operations will undoubtedly be closer to city centers, the complaints from citizens will probably increase. This was vividly brought to mind in New York at the time New York Airways, Inc., (NYA) began operations from the Pan Am roof. The FAA and NYA began receiving complaints. This caused NYA not only to alter their approach and departure routes, but also to curtail their schedule. I bring this out merely to emphasize the serious consequences resulting from noise complaints.

What advantages do the STOL aircraft possess which would help alleviate the noise problem?

STOL aircraft have several things going for them and one or two disadvantages. I'm sure the advantages more than offset the disadvantages. First, let's look at the minuses. Because of the STOL aircraft's slow flight characteristics in the terminal area, the noise will remain with us for a longer period of time. Secondly, since the STOL aircraft will require higher power-to-weight ratios, it is reasonable to assume that additional noise will be generated. There are some tradeoffs here that are quite apparent. For instance, the slow speed can be offset by better maneuverability, and the augmented power can be offset with the ability to reach an altitude more quickly.

With this in mind, let's look at some of the advantages, a few of which I have already touched on.

(1) The distance required to capture and maintain the localizer and glide slope can be shortened. In our limited flight evaluations conducted at our experimental center, we concluded that three miles is ample distance to intercept and capture the localizer and two miles is sufficient distance to stabilize on the glide slope. This contrasts with approximately six miles for the conventional aircraft to perform these same functions.

(2) In four out of the five aircraft evaluated, a $7\frac{1}{2}^{\circ}$ glide path was found acceptable. With this steeper glide path, it is obvious that only in the last stage or the approach will the aircraft be close enough to the ground to create objectionable noise.

(3) Precision offset approaches may offer still another noise abatement procedure. A 20° offset appears to be acceptable for those aircraft evaluated. This would assist in establishing an approach route removed from

the critical noise areas. It would also permit locating STOL strips in areas not now possible with the conventional straight-in approaches.

As an example, it might be possible for an approach down the East or Hudson River away from the built-up city area, as I have depicted on this chart. (Project chart). In addition to alleviating noise, the offset approach could also be utilized to take advantage of any obstacle considerations.

(4) Maneuverability can also assist in noise abatement because of its direct affect on the airspace needed to perform certain maneuvers, such as circling to land, turning missed approaches, final alignment, etc.

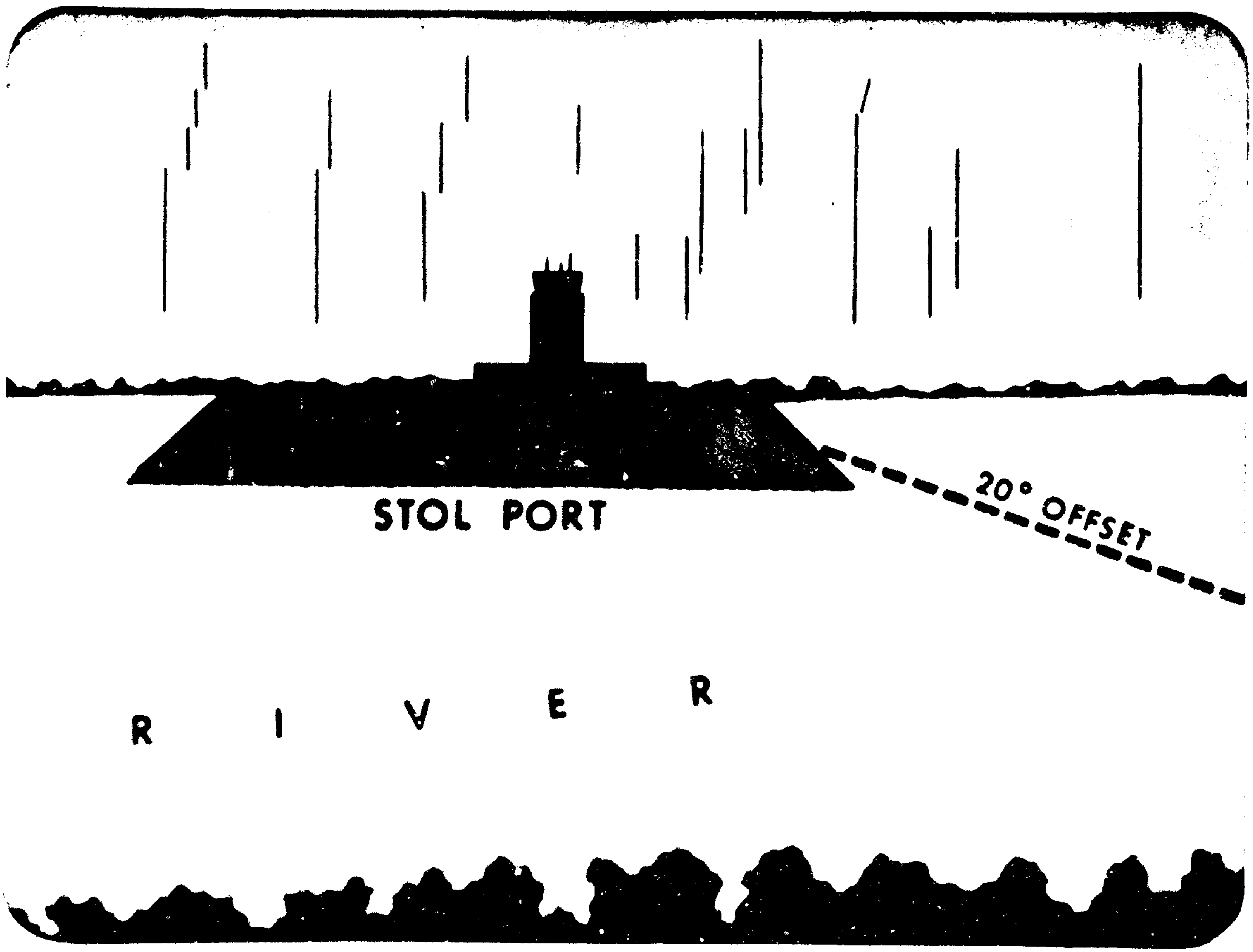
There has been very little incentive in the past in designing a reasonably quiet aircraft. The trend has been to design larger and larger aircraft requiring bigger and/or more engines or both which tends to increase the noise level.

The aircraft noise problem has been building up for some time and the Congressional interest which resulted in the enactment of Public Law 90-411 was not totally unexpected. It is worthy to note that prior and subsequent to the enactment of this law, the FAA has been working with interested parties in formulating the bases of aircraft noise regulations. This is being done with the view of securing substantial and effective noise alleviation with a minimum penalty on the aircraft industry. This will be discussed in more detail at a later presentation.

I recently read in the Armed Forces Journal where the Army and the Advanced Research Project Agency are engaged in a program to determine "what it costs, in weight and performance" to reduce helicopter noise. The tests will attack four main sources of helicopter noise: the main rotor, tail rotor, engine inlet and engine exhaust.

Those aspects of the test related to the engine exhaust and engine inlet should be of vital interest to the STOL aircraft manufacturers and users.

In closing, I would like to say that the success or failure of any STOL operations will be largely dependent on the acceptability of the STOL aircraft by the public. And in this regard, I'm sure a quieter aircraft will help.


STOL PORT
20° OFFSET
RIVER

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THE STOL PORT AND ITS ENVIRONMENT

by

George L. Buley
Airports Service

Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

THE STOL PORT AND ITS ENVIRONMENT

You have heard previous speakers refer to the importance of the STOL port in the overall development of the STOL transportation system. What I would like to do now is talk to you in more specific terms about the STOL port. We, in the Airports Service of the Federal Aviation Administration, have been working for some time on planning, design, and construction criteria for STOL ports. But before I get into the details, I would like to show a slide listing the topics I will cover with you this morning. Slide No. 1 lists six items: Responsibility for STOL port planning, design and construction, the Federal Aid Airport Program, the National Airport Plan, the Interim Design Criteria for STOL ports, Aircraft Noise (and in this case we mean STOL aircraft noise and land use) and finally a Hypothetical STOL Port in a major metropolitan area.

Let's take a look then at the first item. Who is responsible for the development of airports, and, more specifically, a STOL port? Unlike elements in our airspace and ATC system, the airport per se is not a federal function; in other words, the development of the airport is not done by the Federal Government as is the case with the common air navigation system. Although in Airports Service we have the responsibility for development of planning, design, and construction criteria, we do not construct the airports. (The Federal Government owns only three airports: Dulles, Washington National, and National Aviation Facilities Experimental Center.) Also, we do not license airports as such. It is the responsibility of the local authorities to develop their own airports as part of the national system. However, the Federal Government has developed, as a catalyst, the Federal Aid Airport Program.

This program provides financial assistance to communities in the development of their airport as a part of the national development of the system of airports. The Federal aid program was authorized in 1946 and since that time over a billion dollars has been spent in the development of airports across the country. This sounds like a lot of money and it is, but the demand has always exceeded the supply of Federal funds available. This fiscal year, for FY 1970, Congress has appropriated $30 million to aid communities under the program that commences next July 1, 1969. However, over $450 million in requests were received. This givesn you an idea, of course, as to the recognition of the airport needs by the communities of this country and their willingness to produce 50% or more of the cost if Federal aid is made available to them.

The current program of Federal aid does not include any STOL ports; however, STOL ports are eligible under the Federal aid program on the same basis as any other airport. I would also like to point out that Federal aid funds (FAAP funds, as we term them) cannot be used specifically for noise abatement. Nevertheless, they have been used for purchase of property which we call "clear zones"; that is, the area of land immediately off the

end of each runway. (The length of the clear zone will vary according to the category of the airport.) Under the Federal aid program, control of the clear zones is a condit'on to receiving Federal grants. Accordingly, the secondary benefit of having acquired the clear zone is that the land is under local control and that there shouldn't be any problem with aircraft noise in this area.

Next, let's take a look at the National Airport Plan. The FAA, through its Airports Service, issues every year a National Airport Plan. This is a requirement of the Federal Airport Act of 1946. This plan lists specifically by states the location and the development that is needed at each airport as a part of an adequate national system. This development is listed and costed out so that we have a total estimated cost for facilities which are used by the public in the operation of aircraft and which are considered adequate for Federal participation. This cost specifically excludes all buildings that are necessary to any airport's operations. For the first time this year, the National Airport Plan includes STOL ports and 25 are listed as being required in the system. Most of these STOL ports are in the Northeast Corridor and on the West Coast. The 1969 National Airport Plan is pres ntly being formulated and we expect that more STOL ports will be included in the new plan in other metropolitan areas of the country.

Another major function of Airports Service is the development of planning and design criteria. Related to STOL ports, this means that we are responsible for the development of dimensional criteria, lateral clearance, gradients, etc. We've been analyzing data that have been developed by manufacturers, NASA, and our own FAA groups for several years. As a result of these studies, we're convinced the development of a STOL aircraft transportation system has tremendous potential.

One of its primary roles should be in the short-haul transportation of people from one city center to another; for example, from Manhattan Island to the downtown or city center of Washington, D. C. This potential is greatest when it is a separate STOL airport. Such a STOL port would hav certain very definite advantages; one would be that it would give a better service to the passenger, we believe, by reducing total trip time involved, as well as reducing the number of times that a person would have to change modes of transportation. Also, it would have the benefit of relieving airspace and ground congestion at the large airports such as John F. Kennedy International Airport in New York.

In this regard, one airline took a survey of the passengers departing New York City and found that over 40% were destined for other locations within the Northeast Corridor. However, as great as the potential is, we still do not have a STOL aircraft certificated under the tentative airworthiness

standards which were issued by the FAA last July as a result of joint industry/government efforts. Without such a certificated aircraft, or even more importantly, without having a manufacturer committed to the production of a STOL aircraft, it's difficult for us to predict with great certainty the exact criteria needed for the development of a STOL airport. Usually in developing criteria for conventional airports, we have the situation where a manufacturer has at least committed himself to production; the aircraft many times has already been flown in some prototype phase. So we have very good data to work from and we can generally develop with confidence the criteria for runway length, taxiway width, etc. But with STOL we have a different situation than we have had in the past.

Accordingly, last July we issued a Notice entitled: "Interim Design Criteria for Metropolitan STOL Ports." We did this for several reasons. One was that in order to allow development of a STOL transportation system to proceed, we've got to be planning now for a system of STOL ports, and we do want to encourage development of the system. Further, we realize that the FAA acts as a catalyst and a focal point in this system.

We have received considerable pressure from our field offices for the development of these criteria, and of course, as you've seen in commercial publications, there has been a great deal of publicity on proposed STOL ports in several metropolitan areas. So we felt a strong demand to develop STOL port criteria to allow communities to go ahead and plan STOL ports in accordance with the best information available at the present time.

The interim standards that we issued last July are based on information that we had available from manufacturers, NASA, as well as the flight tests at NAFEC that were conducted last year and are still going on. Well, briefly, let's look at the major points of these criteria, realizing that probably most of you have seen them already.

We are recommending that the metropolitan STOL port be planned considering a runway 1500 feet in length and 100 feet wide, with 150 feet safety areas off each runway end. Regarding obstruction clearance planes, that is, the imaginary surfaces related to aircraft operations, we are recommending the approach slope be 20 to 1 and the transitional slope on each side of the runway be on a slope of 4 to 1. Other details are contained in the Notice. If anyone would care to get a copy of this Notice, I would be glad to provide him with one after the presentation.

So far we've covered: STOL Port Responsibility, the Federal aid program, the National Airport Plan, our Interim Design Criteria; but what about

the actual siting of a STOL port? Where might we locate one in order to realize the true potential of STOL? In looking at many metropolitan areas, you'll notice, needless to say, that the land uses are very intense and the siting of any conventional airport would be very difficult indeed. A STOL port does have certain advantages which allow us more flexibility certainly in locating one of these in a metropolitan area. The short runways, the need for less airspace due to the inherent maneuverability of a STOL aircraft, and the steeper obstruction clearance planes, allow greater flexibility in siting. Additionally, because of the shortness of the STOL runway, we feel that in some cases, it may be feasible to site a STOL port on an elevated structure; perhaps on a waterfront or over a railroad yard. However, the fact that a waterfront site may be available does not mean that we can automatically put the STOL port there.

This is only the beginning. The surrounding land uses have a very important effect on the airport and, of course, the airport itself will have an important effect on these land uses. In particular, we want to emphasize that aircraft noise will undoubtedly be a primary factor in siting a STOL port. Land uses that we believe should be avoided are: residential, schools, hospitals, and noise-sensitive commercial land uses. On the other hand, land uses that are considered compatible are transportation ways; that is, railroads, highways, rivers, lakes; industrial, so long as they don't interfere with the airport through production of smoke or electronic signals, and also commercial and recreational uses to a certain extent. The innermost area under the approach zone is the most critical.

I mentioned previously that under the Federal aid program a condition to receiving a Federal grant is that the local authority control the runway clear zones. In the case of a STOL port, the clear zone is defined as being the first thousand feet beyond the end of each runway. Control of this clear zone area should be effective in helping to achieve a compatible land use situation. Also, if the local authority will institute height restriction zoning and implement comprehensive land use zoning, then many future problems related to land use can be precluded. Also of great importance is the planning of surface transportation so that there is a convenient interchange between the air and surface modes of transportation including rapid transit systems, taxis, buses, and automobiles at the STOL port.

I would like to illustrate what we've been talking about through use of a hypothetical STOL port. You see on the screen Slide No. 2 which is entitled, "Hypothetical Metropolitan STOL Port." Let's review the environment of the STOL Port and the imaginary surfaces related to obstruction clearance. The STOL port is here, very conveniently located on the waterfront of the Uptha River. Adjacent to it is an expressway; just beyond

that is a railroad line and to the west is a railroad marshalling yard. The obstruction clearance planes that I mentioned previously are the gray areas extending out to the east and west. Across the river is a residential area and immediately to the south of the STOL port we have various land uses as you might expect in an urban or congested area. The red color denotes commercial use. The blue is industrial. The brown is residential-multiple unit; that is, apartment buildings. The green indicates recreational or park; and the orange color indicates institutional (schools).

As you can see, the approaches to and from the airport are either over the river or over the railroad marshalling yard and the industrial area. This is an idealized situation. But in order to give you a better idea how a hypothetical STOL aircraft might affect the nearby land uses, we've drawn up a noise contour as an overlay. As you can see, this overlay is centered on the airport. In constructing the contour, one of the primary assumptions was that there would be an equal number of landings and takeoffs in each direction. The resultant line or contour is called a 30 NEF contour. NEF is an acronym for noise exposure forecast. I won't get into this now except to say that within the contour is the area that we are most vitally concerned with. We'll assume that outside the contour there won't be any significant problem due to aircraft noise. Later in the day, Mr. Sperry from the Office of Noise Abatement, will discuss the NEF contours further.

The NEF contour on the overlay extends primarily over an uninhabited area: the railroad yard, the river, and only to the south in the commercial area and part of the industrial area do we have the noise contour affecting the land use. However, this should be no obstacle. For the location and for the assumed STOL aircraft we would not anticipate any siting problem due to land use.

Next, let's take a somewhat less idealized case. Let's assume that the waterfront site is not available. Let's assume that the only site where it is feasible to locate a STOL port is in the industrial area. What happens when we put our contour in the blue area? As you can see, a great deal more land is affected by the noise contour. In fact, we have a two-pronged problem here. By locating the STOL port in the industrial area on an east-west orientation, the southern-most part of the noise contour extends into a multiple residential area; that is, the apartment area. Also, the clear zone related to the east runway approach lies outside of the industrial area. This could be a major problem.

Let's go one step further and assume that wind conditions require the runway to be oriented more to the northwest-southeast as shown here. The

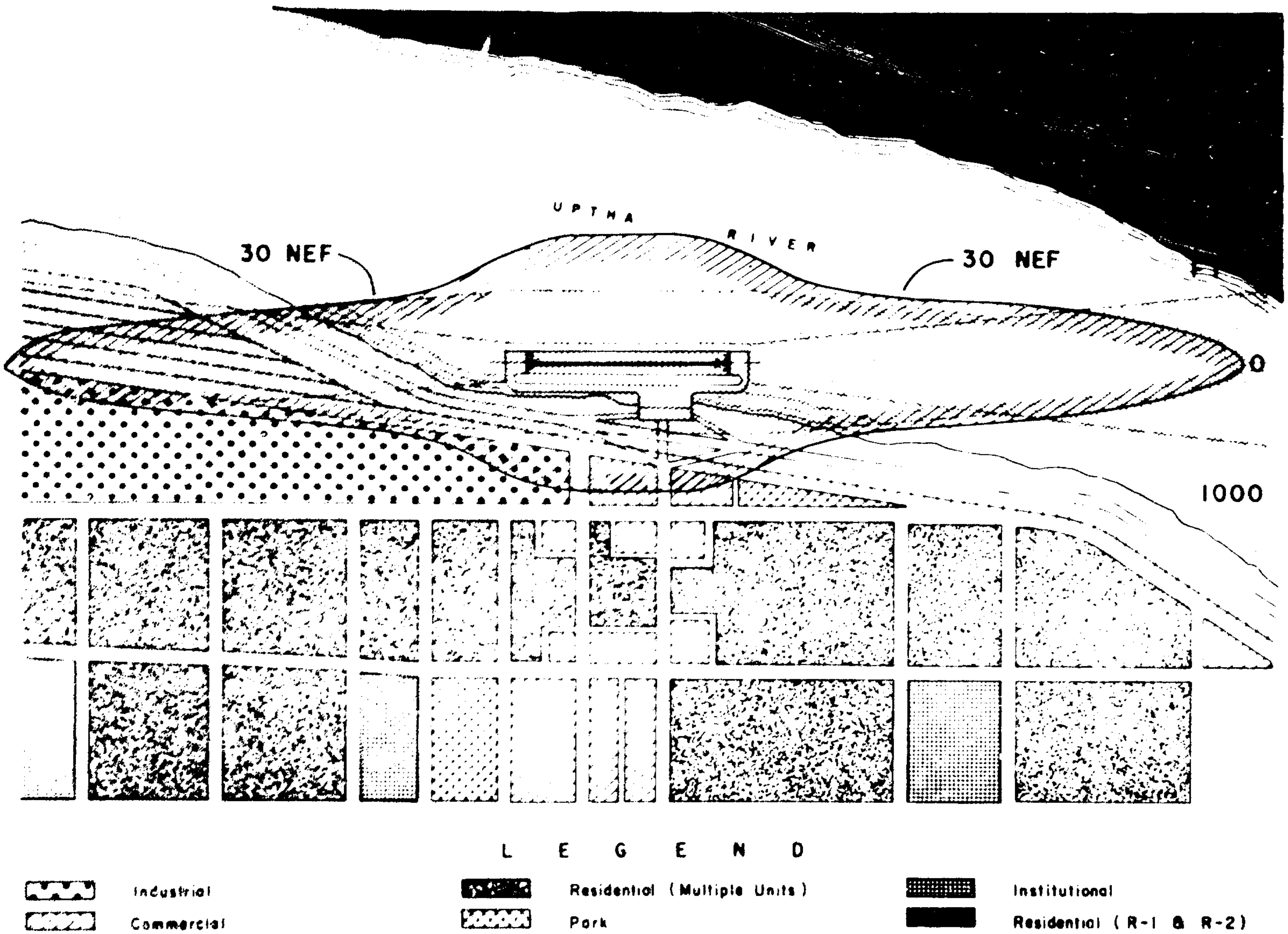
situation is even worse than it was before. The easterly portion of the NEF area is now over a very large, predominantly apartment area. The southern-most area of the NEF contour also includes apartment area. Again, the clear zone for the easterly approach lies outside the industrial area and extends over the road and an apartment area. These conditions would probably preclude further consideration of this site.

In summary, what I am attempting to say is that the importance of aircraft noise in relation to the siting of a STOL port cannot be over-emphasized. This will be one of the primary factors in being able to find an acceptable site for a STOL port in a metropolitan area. Accordingly, we strongly believe that the process for development of a STOL aircraft must take into account the total environment in which this vehicle will operate. When the aircraft is developed, it must be able to operate in the total system considering not only the airways and the passengers but also the airport environment which will be greatly affected by aircraft noise.

STOL PORTS

* RESPONSIBILITY FOR STOL PORT PLANNING, DESIGN, AND CONSTRUCTION
* FEDERAL-AID AIRPORT PROGRAM (FAAP)
* NATIONAL AIRPORT PLAN
* INTERIM DESIGN CRITERIA
* AIRCRAFT NOISE AND LAND USE
* HYPOTHETICAL STOL PORT

Figure No. 1



METROPOLITAN STOL PORT

Figure No. 2

AIR TRAFFIC CONTROL NOISE ABATEMENT

by

Myles H. Reynolds
Air Traffic Service

Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

AIR TRAFFIC CONTROL NOISE ABATEMENT

Over the period of the past few years, air traffic controllers have been treated to a pretty large press. They've received quite a bit of public attention. Some of this publicity apparently has caused misunderstanding. Obviously, some people believe that the controller has something approaching an absolute authority over aircraft in his area. They seem to believe that this authority sometimes transcends that of the pilot and includes the decision as to whether the pilot should or should not fly. Along with this authority, it is quite logical to them that the controller must accept attendant responsibilities, including that for the noise generated by the aircraft in his control jurisdiction.

Controllers do have a part of the action. They have a responsibility to carry out their part of the total effort and are constantly aware of that responsibility.

Similarly I am certain that everyone here today is well aware of the fact that noise abatement has a definite effect upon the services provided by air traffic control. It affects the services provided by controllers and it affects individual controllers personally. Similarly our regional and headquarters offices are well aware of the problem and attendant responsibilities. If nothing else, we are constantly reminded by those cards and letters that keep coming in. We have long faced the fact that nearly all aircraft make noise and most of that noise is objectionable to some people. We also realize that sometimes noise is merely the tangible subject of a complaint and that fear is the actual motivation for it.

You are aware of the past and the present means applied to minimize the effects of aircraft noise on airport neighbors; traffic pattern adjustments, formal and informal runway use programs, including preferential runways, airport arrival and departure procedures and flight paths, navigation aid location and relocation, electronic landing and installation and use, visual approach aids systems and others. Most have had to be cooperative efforts since gains in the form of reduced noise exposure or intensity have not been made without cost. The price paid, however, is in efficiency of operation; not safety. The latter cannot and has not been compromised. If it were to be condoned, any compromise with safety would affect not only those in the air but also those on the ground who object to the noise.

Over the years, noise abatement has been accomplished by selection of runways whose use results in arrival and departure flight paths being over the less densely populated area to the extent feasible. Sometimes this works relatively well until we find that a mink farm is located in that same otherwise unpopulated rural area or a school or hospital in an area occupied primarily by light but compatible industry. Generally, flight path adjustments resulting in arrival/departure paths over

industrial areas have reduced noise complaints. Airports located adjacent to a large body of water have sometimes produced the same results. However, the physical relationship of most airports to the nearby areas that offer the means for noise abatement benefits generally has not been planned for that specific purpose and, at best, usually offer only a partial solution. Even with a new airport, the absence of a noise problem seldom exists and if it does, not for long.

Unless some appreciable change in the aircraft takes place, we in air traffic control expect no great difference between future STOL noise problems and methods of resolution and those of today's conventional aircraft. The problem will exist with STOL operations at today's airports and at STOL ports located in the city's business or outlying areas. The ability of STOL aircraft to take off and land on less concrete does not change the fact that they produce noise while doing it. They will still be required to fly some form of a traffic pattern at the airports they use. Instrument approaches and departures will be required. While the steeper descent and climb capabilities may assist, it alone will not resolve the problem. Let me cite examples.

When STOLs are operated at a CTOL airport, the operators and air traffic control will wish to gain every possible advantage their capabilities may provide. The use of STOL runways and flight paths separated from those used by the CTOL aircraft may provide the way to increased operations. But, it also may result in climb/descent over areas not previously exposed to directly overhead takeoff/landing operations. There is a greater probability the same will occur at the newly established STOL port. Adequate site selection and planning will be extremely important and certainly can minimize the problem but it will not be eliminated. The noise, or lack of it, will still depend to a great degree upon the aircraft, the flight path planning and operational requirements and procedures.

Using Mr. Buley's STOL port diagram* again, let's see what might occur. The runways parallel the river. Any IFR precision approach courses would be of necessity aligned with or as near as possible, parallel to the runway. An individual final approach could be contained within about three to four miles of the runway threshold. Also, an IFR departure could turn from the takeoff heading in a relatively shorter distance if desirable or necessary. Thus, the exposure area may be smaller than that associated with CTOL operations. Within that exposure area, the increased vertical maneuvering capability of the aircraft may permit a steeper IFR approach path; also, a steeper climb angle after takeoff may be expected. These capabilities could result in further reduction of the objectionable levels of noise.

*Figure 2, page 81, of Mr. Buley's paper.

The VFR traffic patterns for the STOL port, while in part similar to the IFR courses, normally must accommodate random direction routes to and from the airport area. For example, an aircraft inbound from the east to the STOL port could easily fly over the river, land to the west and remain totally on the most beneficial noise abatement route. However, if an easterly landing is required, a downwind and base leg must be added to the flight path. A standard left traffic pattern appears to be an obvious best answer with the downwind and base legs over the river. Arrival from and landing to the west appears to dictate a nonstandard right hand pattern over the river. While the east/west arrival/departure routes seem obvious, the north/south routes might dictate the use of selected corridors to and from the river in order to avoid regular flight over areas particularly sensitive to the noise. This alone is usually not too easy but it can be made even more difficult by the necessity to avoid airport traffic areas and traffic patterns of other airports, obstacles, restricted areas and other airspace that necessity or good sense tells us not to use.

The factors applied for noise abatement are not for primary benefit of the aircraft operator or ATC. They don't help the operator make a schedule nor do they make the controller's primary task any simpler. However, it is a fact that an industry and system built to serve the public would not long exist if it totally alienates those who make that existence and growth possible. We can't afford to assume that people will become used to the noise and the problem will go away. Nor with the growth in size and required power of aircraft should we assume that the airport neighbor will take up the practice of cutting his finger to prepare himself for a forthcoming amputation.

We have a mandate to seek and implement means to provide for the control and abatement of noise. Past efforts have produced results. Some have been accomplished simply by having more consideration for the neighbor on the ground. Others have involved costs of various kinds. We in ATC see no immediate simple solution that will suddenly relieve any of us from future increased efforts. We shall continue to work within the agency and with all responsible industry, government and citizen groups to minimize the effects of aircraft noise on the public. Working together, not just with each other, we believe reasonable results can be achieved.

NOISE EVALUATION FOR CERTIFICATION

by

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Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

NOISE EVALUATION FOR CERTIFICATION

INTRODUCTION

The Federal Aviation Administration, in response to Public Law 90-411, has begun the rulemaking process leading to the certification of aircraft for noise. The basic element in the regulation criteria is the noise evaluation measure designated as Effective Perceived Noise Level, EPNL, which is a single number evaluator of the subjective effects of aircraft noise on human beings. Simply stated, EPNL consists of instantaneous perceived noise level corrected for tones and duration. EPNL is also the primary element in determining cumulative noise environments in accordance with the methodology called Noise Exposure Forecast, NEF.

EPNL CALCULATION

Three basic physical properties of sound pressure must be measured; level, frequency distribution, and time variation. More specifically, the instantaneous sound pressure level in each of 24 one-third octave bands of the noise is required for a number of consecutive increments of time during the aircraft flyover. The calculation method, shown in Slide 1, which utilizes physical measurements of noise to derive subjective response, consists of the following five steps:

1. The 24 one-third octave bands of sound pressure level are converted to perceived noisiness by means of a noy table. The noy values are combined and then converted to instantaneous perceived noise levels.

2. A correction factor is calculated for each spectrum to account for the subjective response to the presence of the maximum tone.

3. The tone correction factor is added to the perceived noise level to obtain tone corrected perceived noise levels at given instants of time. The instantaneous values of tone corrected perceived noise level are plotted with respect to time and the maximum value is determined.

4. A d[illegible]tion correction factor is computed by integration under the curve of tone corrected perceived noise leve[illegible] time or by using an alternate approximate method.

5. Effective perceived noise level is determined by the algebraic sum of the maximum tone corrected perceived noise level and the duration correction factor.

The FAA Office of Noise Abatement recognizes that the five-step procedure is not complete and that more research is necessary on human response to

noise in order to make the effective perceived noise level concept applicable to a wider range of sounds including sonic boom. The ultimate goal is to develop an objective procedure that will accurately evaluate the subjective effects of noise from all current and future transportation equipment as well as current aircraft, including high bypass engine, V/STOL, and supersonic aircraft, and automobile, truck, railway, and air cushion ground vehicles. Considerable noise abatement research programs and studies which have an influence on effective perceived noise level have been performed, are presently underway, and are in the planning stage.

EPNL EVALUATION FACTORS

As shown in Slide 2, the present form of effective perceived noise level evaluates four factors of the noise signature; level, broadband frequency distribution, maximum tone, and duration. These factors may need adjustment for special conditions, and other factors may be important as well. For example, noise with low frequencies and high intensities, spectra containing combinations of discrete and broadband frequencies at various time durations, Doppler shift, speech interference, multiple tones, harmonic content, and the influence of slowly varying lift pressures from large aircraft flyovers at low altitudes. These characteristics and others ultimately will be investigated and the effective perceived noise level concept extended to include all influential factors.

Of particular interest for STOL aircraft design is the possibility that the noy tables should have lower noy values at the low frequencies. Also, tone corrections should be reconsidered for frequency dependence. Low frequency tones, such as produced by propellers are possibly less annoying than high frequency tones from turbofan engines. Furthermore, propellers which, in general, have lower fundamental frequencies than turbofans, have the potential for generating noise with greater harmonic content within the audible frequency range. It is conceivable that for two spectra with the same energy content, the one with the greater harmonic content would be less annoying.

NOISE SPECTRA

An example of an instantaneous noise spectrum for a turbojet engine is shown in Slide 3. The spectrum is relatively smooth indicating broadband noise with no appreciable tones. The overall sound pressure level is directly related to the noise energy and equals 97 decibels. The instantaneous perceived noise level and tone corrected perceived noise level are subjective measures and are identical because of the absence of tones. They exceed the overall sound pressure level by 6.9 decibels.

An example of an instantaneous noise spectrum for a turbofan engine is shown in Slide 4. The spectrum contains pronounced irregularities due to

a multiplicity of discrete frequency components or tones. In this case, the tone corrected perceived noise level is two decibels greater than the perceived noise level and exceeds the overall sound pressure level by 14.3 decibels. It is interesting to note that the turbofan engine has less audible noise energy than the turbojet engine to the extent of 4.5 decibels but is more annoying to the extent of 2.9 perceived noise decibels.

NOISE FLYOVER

The maximum tone corrected Perceived Noise Level, PNLTM, is the maximum value determined from a smooth curve of the values of the tone corrected perceived noise level, PNLT, plotted against the flyover time, t, as shown in Slide 5. Half-second time intervals, Δt, will usually be small enough to obtain satisfactory accuracy. The duration time, d, is the time interval between the limits of t(1) and t(2) defined by a specified increment, h, to be subtracted from PNLTM. Usually 10 dB is sufficient to define an adequate noise time history.

Three examples of noise flyover curves are shown in Slide 6. These shapes, rectangle, trapezoid, and triangle, are not representative of real flyover curves and are used simply as examples for illustrating the results from using the integration and approximation calculation procedures. The ordinates of these figures are the tone corrected perceived noise level, PNLT. The abscissa is the flyover time, t, and the values chosen are completely arbitrary. The duration time, d, for all three cases is 15 seconds which would yield an approximate duration correction, D, of zero. The integrated duration corrections are given for each case and it is seen that only for the trapezoid case are the approximate and integrated duration corrections equivalent. The results indicate that the integrated duration correction will be greater than the approximate when the flyover curve has a flatter shape than the trapezoid shown and will be less than the approximate when the flyover curve is sharper than the trapezoid.

Slide 7 illustrates an actual takeoff noise flyover curve for a DC-8 at 980 feet altitude. The integrated duration correction is -3 decibels for a duration time of 9.5 seconds. The approximate duration correction is -2 decibels which would yield an effective perceived noise level one decibel larger than if the duration correction were obtained by integration.

Slide 8 illustrates the landing noise flyover curve for the DC-8 at 305 feet altitude. The integrated duration correction is -3.5 decibels for a duration time of six seconds. The approximate duration correction would be -4 decibels which, in this case, would yield an effective perceived noise level 0.5 decibels less than if the duration correction were obtained by integration. This is an unusual example and the fact that the integration method produces a larger value for EPNL results from the flat, nearly rectangular, shape of the flyover curve.

Generally, landing noise flyover curves have sharper configurations such as that shown in Slide 9 for the landing noise flyover curve of a 727 at 358 feet altitude. For this case, the integration and approximation duration corrections are -5 and -4 decibels respectively for a duration time of six seconds. The integration procedure thus yields an effective perceived noise level one decibel less than the approximation procedure.

EPNL PREDICTION

Slide 10 shows the results of measured flyover data plotted as the difference between effective perceived noise level (using the integrated duration calculation) and maximum perceived noise level versus flyover altitude or slant distance. Superimposed on the graph is a curve used by various members of the Aerospace Industries Association for prediction purposes. For most of the data, the AIA curve will predict too large a value for effective perceived noise level.

NEF METHODOLOGY

Effective perceived noise level is an evaluation measure for noise at specified locations generated by individual aircraft. As such, it is the basic element not only in the regulation criteria, but also in determinations of cumulative noise environments. A methodology has been developed called Noise Exposure Forecast, NEF, which includes EPNL as the primary element as shown in Slide 11. NEF provides a mechanism for calculating a single number rating of the cumulative aircraft noise intruding into a community. Additional factors included in the NEF calculation procedure are the effects of various aircraft types, flight profiles, frequency of operations, operating procedures, mix of all four, runway utilization, and time of day of operations.

Slide 12 presents an example of 30 and 40 NEF contours generated by a mix of aircraft operating in a single direction from one runway on a typical large mid-continent airport. This example represents NEF "footprints" for conventional aircraft operating from one runway without applying any noise abatement procedures. The results of the computations for other runways and runway utilizations at the same airport would be superposed to form NEF contours for the entire airport complex.

The NEF contours permit the land areas enclosed within them to be evaluated for various types of use, compatible with the noise exposure. Not the least important, is the information available to the building designer for providing appropriate sound insulated structures. It is generally accepted that land areas exposed to less than 30 NEF will not have major noise problems. Building structures used for sensitive activities such as schools, churches, hospitals, and auditoria, may need some extra noise insulation consideration but the problems, if they exist, can be handled in a routine manner.

CONCLUDING REMARKS

The primary element in any procedure for certificating aircraft noise is the evaluation measure upon which the criteria is based. Aircraft noise signatures, which involve interrelated spectral, temporal, and spacial functions of sound pressure, are so complex that the search for a suitable single number noise evaluator has been long and difficult. The end result to date, considered the best current state-of-the-art by the FAA Office of Noise Abatement, is effective perceived noise level, EPNL.

This opinion, however, is not shared by some members of the aviation community who would prefer a simpler evaluator such as perceived noise level, PNL. This simpler measure responds to the effects of frequency and level but does not permit the adjustments for the annoyance of strong tones and long durations that are inherent in EPNL.

It is extremely important that the noise evaluator chosen for certification be versatile in the sense that it recognizes the annoyance effects known today and is capable of modification or refinement for potentially obnoxious sounds of the future. EPNL is such a unit; not complete and not exact, but the best available at the present time. Furthermore, it is not too complex and it is suitable for prediction.

EPNL is also the basic element in determining community noise exposure. Land use and building construction will be strongly influenced by this measure. Hence, it is vital that the best state-of-the-art be used and refinements made and additional factors included as soon as they are validated. This will be particularly applicable to land areas and buildings in the vicinity of STOL ports.

REFERENCES

Sperry, W. C., "Aircraft Noise Evaluation," Federal Aviation Administration, Report FAA-NO-68-34, September 1968.

Bishop, D. E., and Horonjeff, R. D., "Procedures for Developing Noise Exposure Forecast Areas for Aircraft Flight Operations," Federal Aviation Administration Report FAA-DS-67-10.

1. INSTANTANEOUS PERCEIVED NOISE LEVEL, PNL

2. TONE CORRECTION FACTOR, C.

3. TONE CORRECTED PERCEIVED NOISE LEVEL,

$$PNLT = PNL + C$$

& MAXIMUM TONE CORRECTED PERCEIVED NOISE LEVEL, PNLTM

4. DURATION CORRECTION FACTOR, D,

BY INTEGRATION,

OR BY APPROXIMATION

5. EFFECTIVE PERCEIVED NOISE LEVEL,

$$EPNL = PNLTM + D$$

SLIDE 1

FIVE-STEP CALCULATION PROCEDURE

CURRENT EPNL FACTORS

- LEVEL
- BROADBAND FREQUENCY DISTRIBUTION
- MAXIMUM TONE
- DURATION

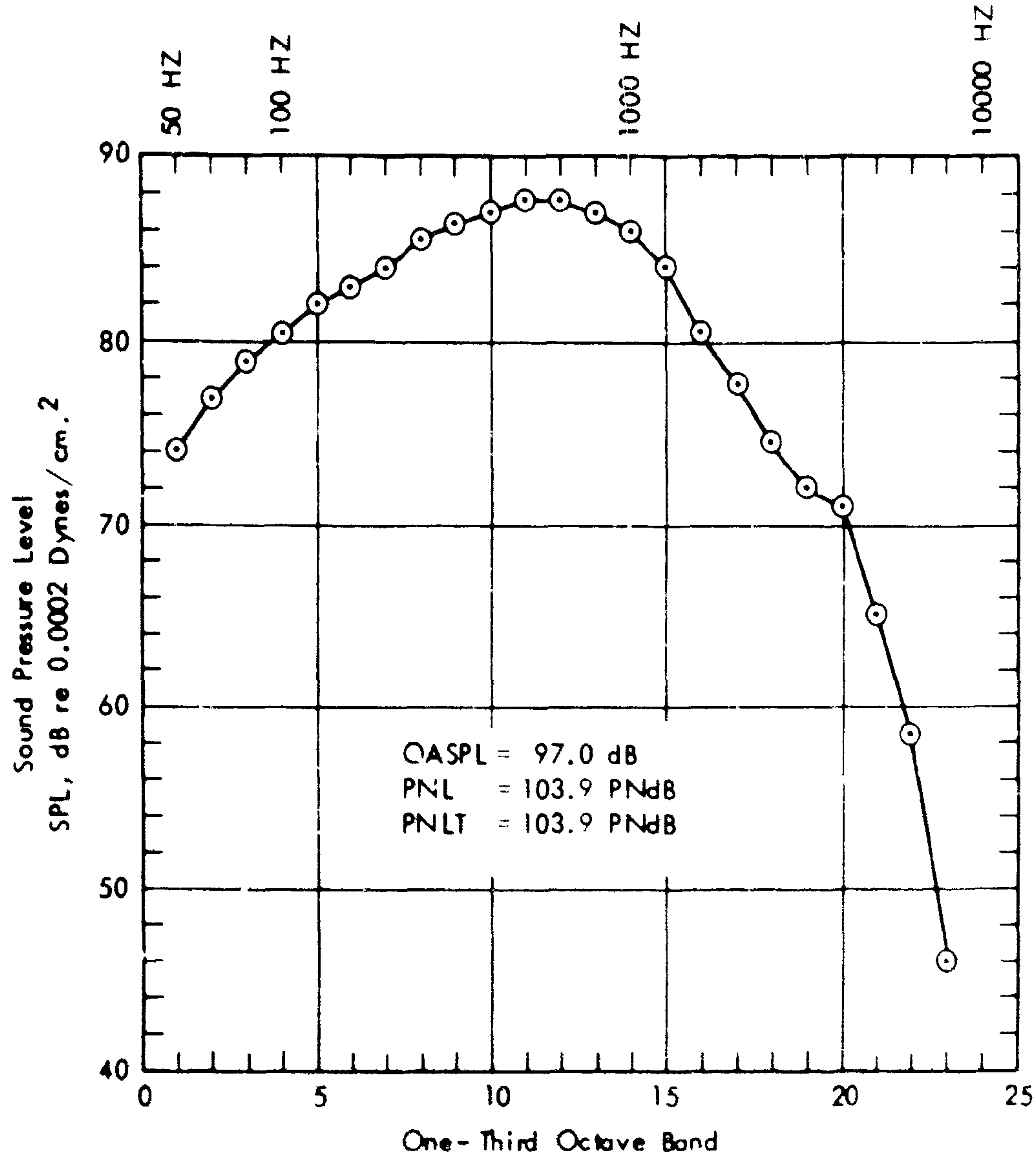
FUTURE EPNL CONSIDERATIONS

- LOW FREQUENCIES & HIGH INTENSITIES
- TEMPORAL & SPECTRAL COMBINATIONS
- DOPPLER SHIFT
- SPEECH INTERFERENCE
- MULTIPLE TONES
- HARMONIC CONTENT
- LIFT PRESSURE

SLIDE 2

EFFECTIVE PERCEIVED NOISE LEVEL

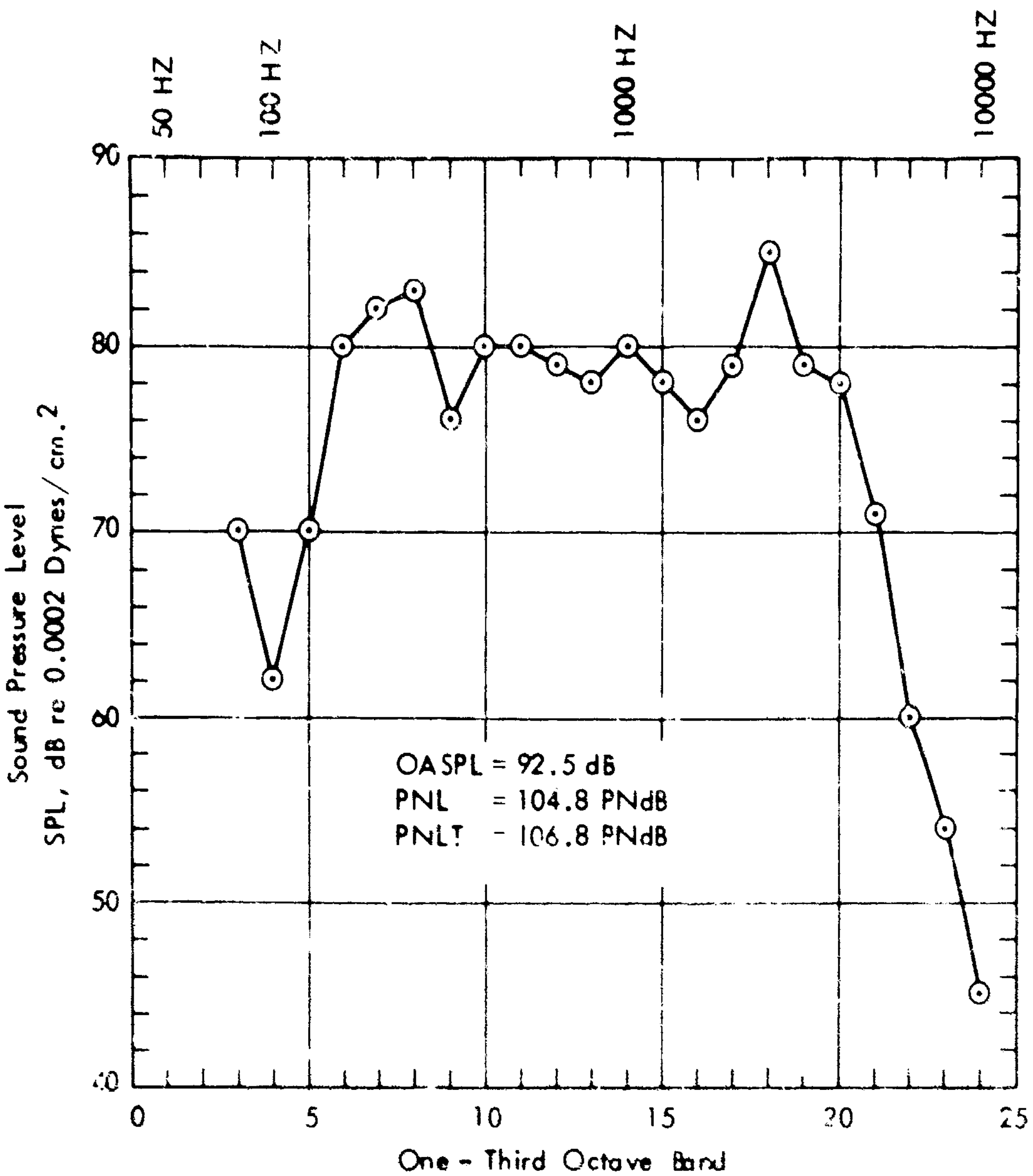
EVALUATION FACTORS



SLIDE 3

SOUND PRESSURE LEVEL SPECTRUM

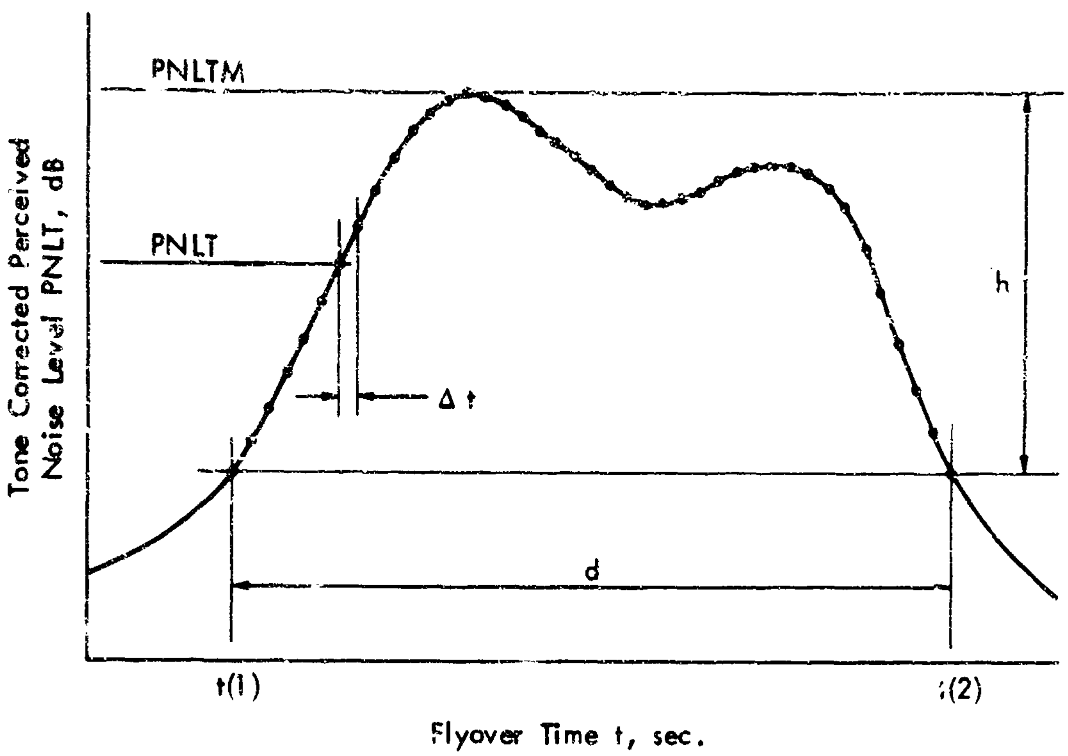
OF A TURBOJET ENGINE



SLIDE 4

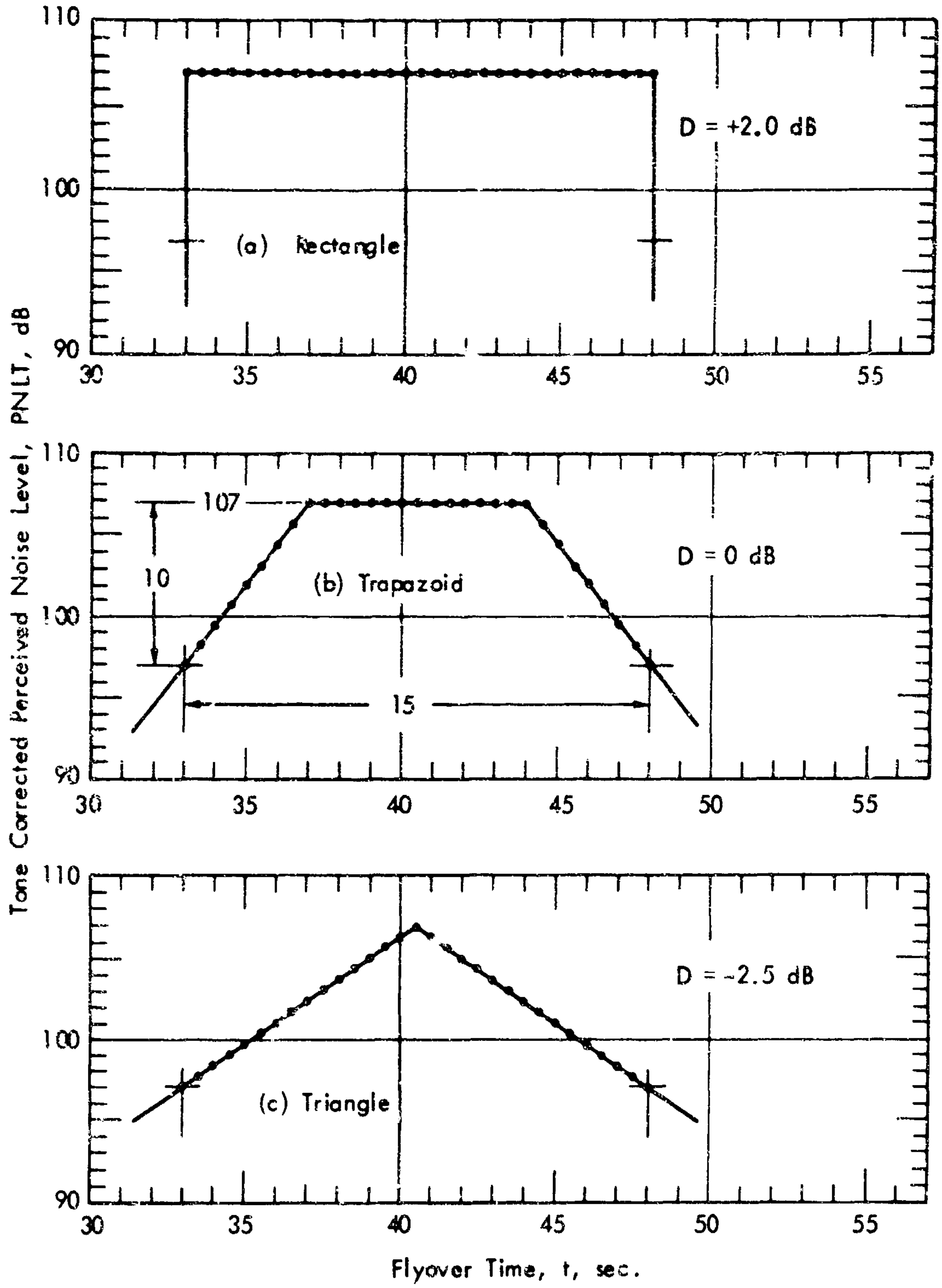
SOUND PRESSURE LEVEL SPECTRUM

OF A TURBOFAN ENGINE



SLIDE 5

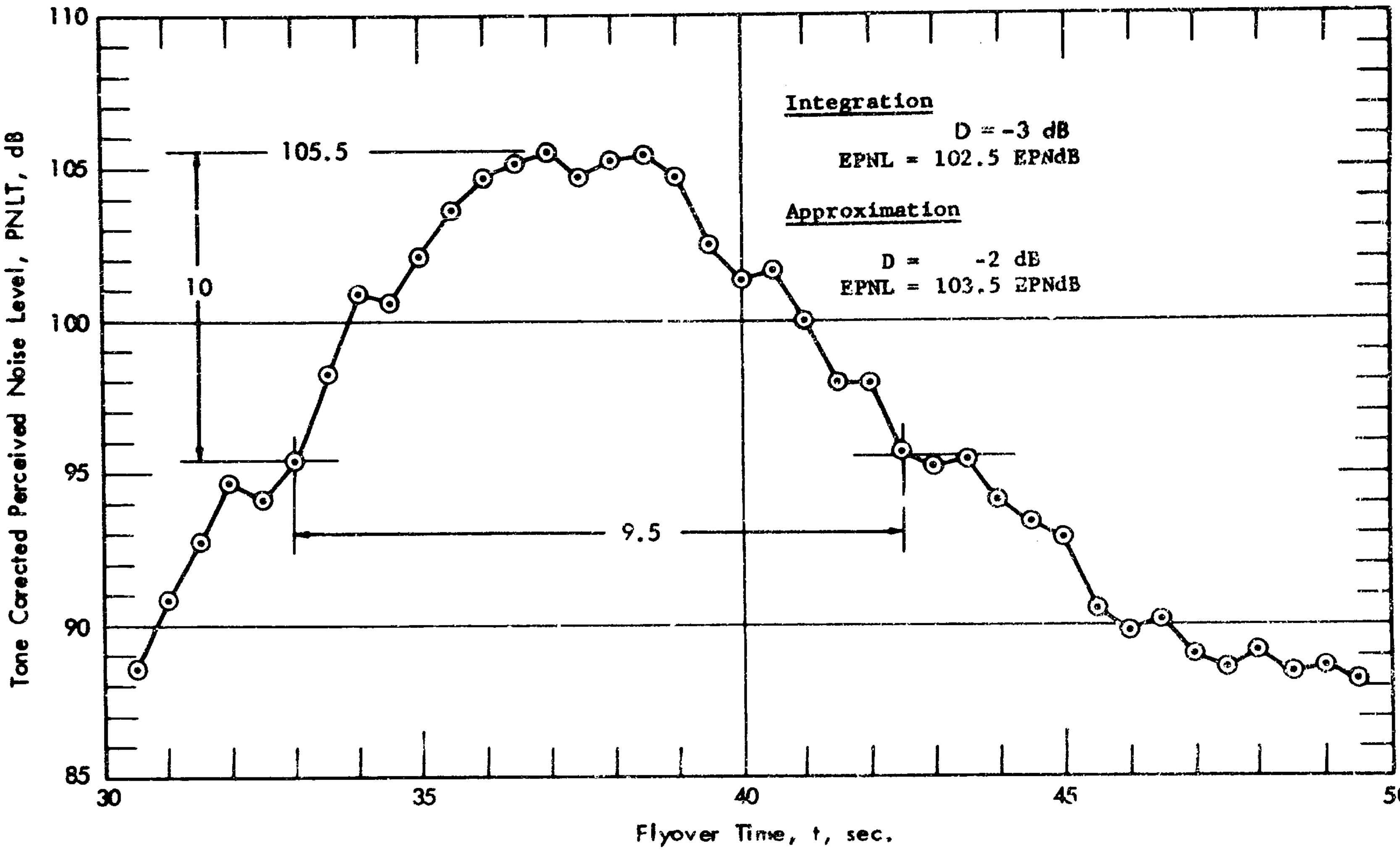
PERCEIVED NOISE LEVEL CORRECTED FOR TONES AS A FUNCTION OF AIRCRAFT FLYOVER TIME



SLIDE 6

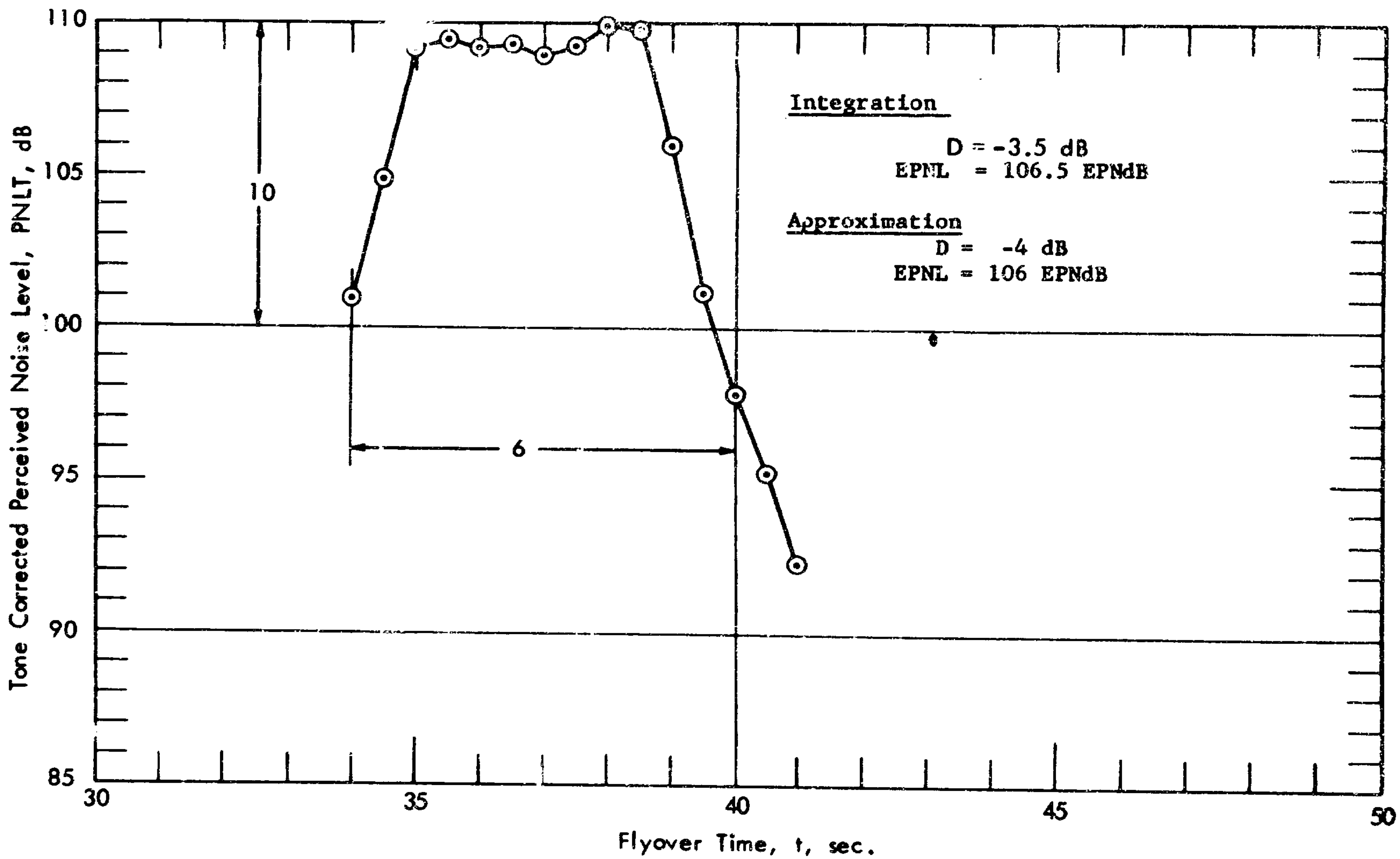
NOISE FLYOVER CURVES WITH 15-SEC. DURATION TIME

APPROXIMATE D ≈ 0



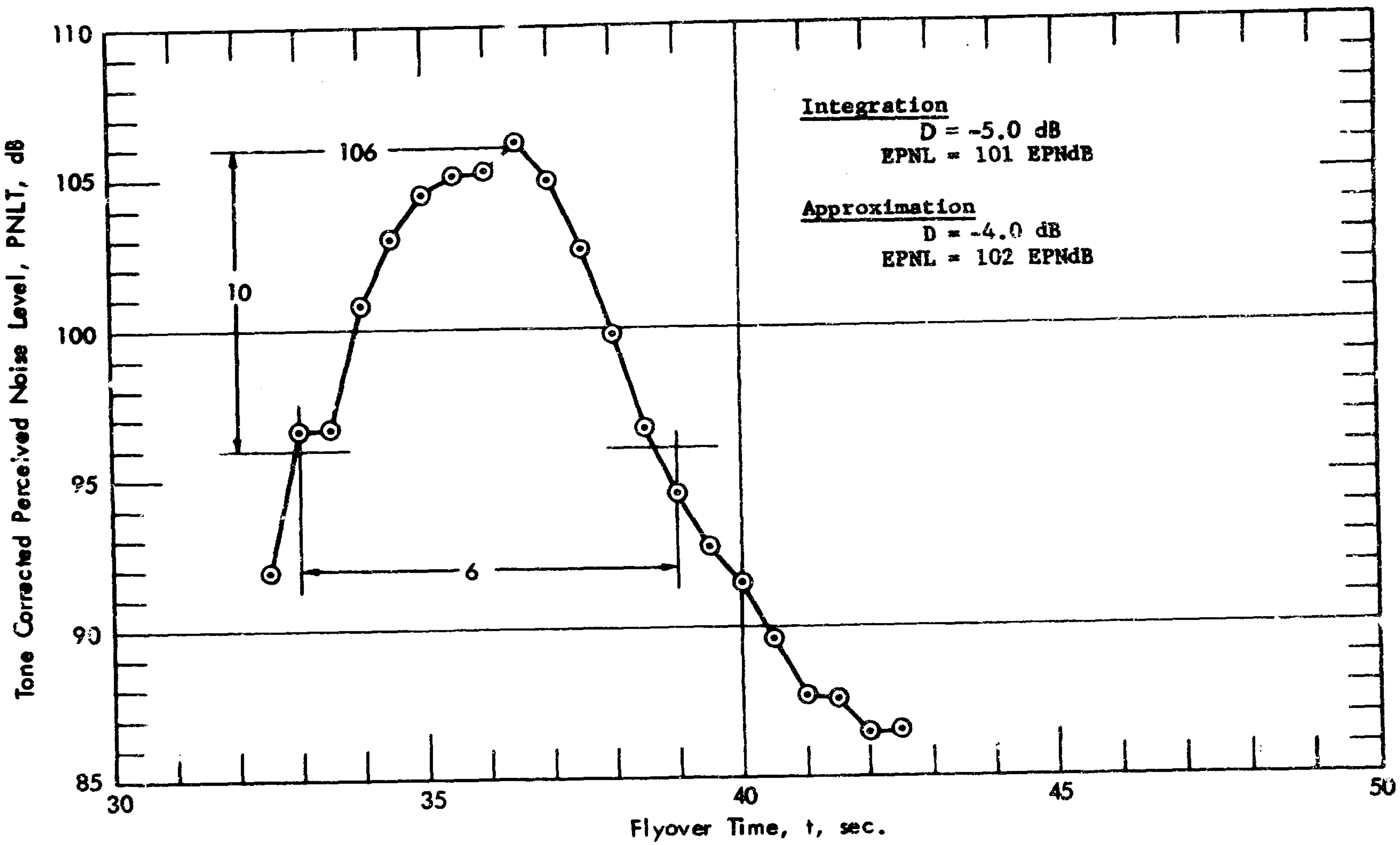
SLIDE 7

NOISE FLYOVER CURVE FOR A DC-8 TAKEOFF AT 980 FT. ALTITUDE



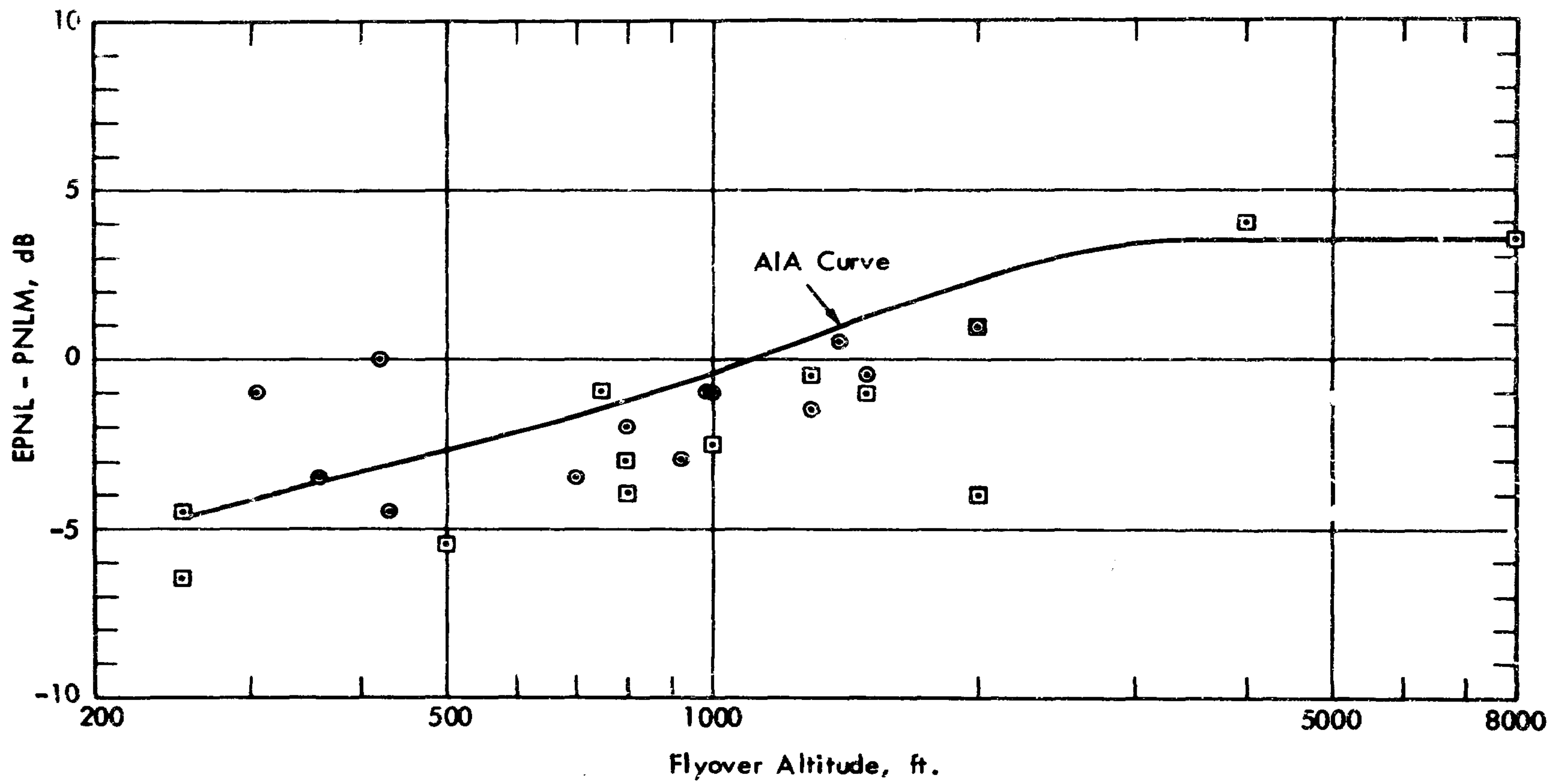
SLIDE 8

NOISE FLYOVER CURVE FOR A DC-8 LANDING AT 305 FT. ALTITUDE



SLIDE 9

NOISE FLYOVER CURVE FOR A 727 LANDING AT 358 FT. ALTITUDE



SLIDE 10

EPNL (INTEGRATION) AS A FUNCTION OF MAX. PNL

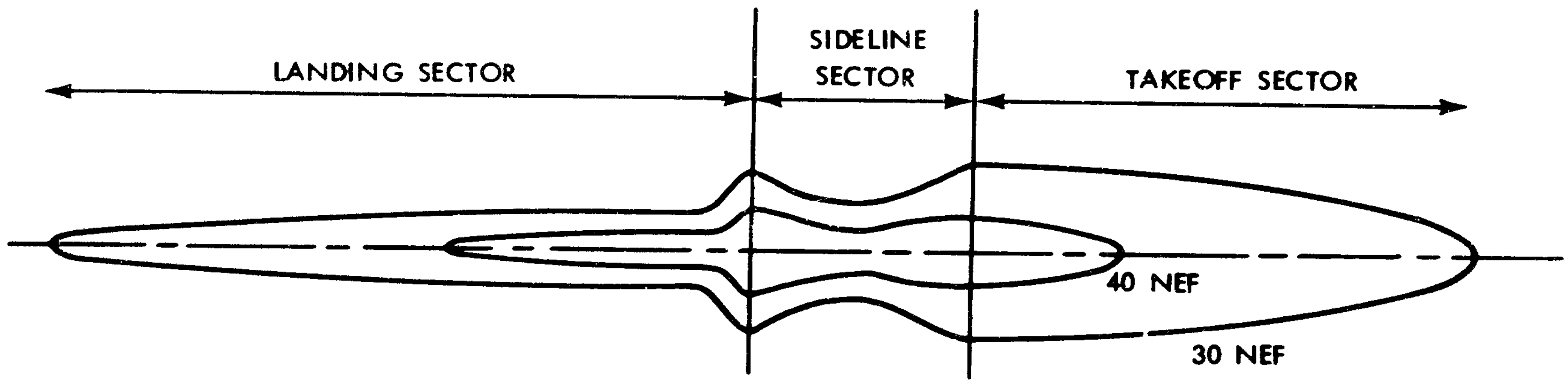
AND FLYOVER ALTITUDE

- EFFECTIVE PERCEIVED NOISE LEVEL, EPNL
- AIRCRAFT TYPE
- FLIGHT PROFILE
- FREQUENCY OF OPERATIONS
- OPERATING PROCEDURES
- MIX OF TYPE AND OPERATIONS
- RUNWAY UTILIZATION
- TIME OF DAY OF OPERATIONS

<u>SLIDE 11</u>

<u>FACTORS INCLUDED IN COMPUTATIONS</u>

<u>FOR NOISE EXPOSURE FORECAST, NEF</u>



- ONEWAY RUNWAY UTILIZATION
- NORMAL CLIMB GRADIENT
- NORMAL 3° GLIDE ANGLE

SLIDE 12

NOISE EXPOSURE FORECASTS FOR A TYPICAL LARGE MIDCONTINENT AIRPORT RUNWAY

SOME DEVELOPMENTS IN THE NOISE REDUCTION IN DUCTED PROPELLERS AND FANS

by

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Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

SOME DEVELOPMENTS IN THE NOISE REDUCTION IN DUCTED PROPELLERS AND FANS

Many ways are known to reduce noise; however, these methods will usually increase the propulsion system weight, decrease performance, or both. When noise reductions are cited here, it should be remembered that there may be a penalty associated.

Figure No. 1 restates the primary noise sources in fans. If all stage interactions and rotational noise are eliminated, fan noise will probably be acceptable. The first part of this paper will address stage interaction. Three of the four charts that follow came from a study by the General Electric Company, under contract to NASA, on means of reducing the noise generated by lift fans. These particular results are analytical. Figure No. 2 shows the relative perceived noise level versus the spacing between the rotor and the stator. This particular fan had about one quarter chord spacing. By increasing spacing to two chords, noise was reduced about 5 PNdB. The ratio of stator vanes to rotor blades is an important parameter in the propagation of interaction noise between the rotor and the stator. Figure No. 3 shows the relative perceived noise level as a function of the number of vanes. This particular fan had 36 vanes and 66 blades. To reach a vane-to-blade ratio of two requires about 130 vanes. With 130 vanes, the noise is reduced about 5 PNdB. Another means of reducing rotor-stator interaction noise is to make the rotor vanes non-radial. Figure No. 4 shows model tests of the effect of stator vane lean on noise. By leaning the stators 60 degrees, sound pressure level was reduced by 16 dB. This would appear to be a very effective means of reducing noise.

Rotational noise can be reduced by increasing the number of blades; however, with the compressor, this can be done only within constraints placed upon blade aspect ratio and solidity. Figure No. 5 shows the effect of increasing number of blades within the aforementioned constraints. Perceived noise level is shown as a function of number of blades. This particular fan rotor had 40 blades. Doubling the number of blades decreased noise about 4PNdB. When all of these noise reducing techniques are employed in the lift fan design, and acoustic treatment is applied to both exit louvers and the available air flow paths, noise is reduced as shown on Figure No. 6. Perceived noise level is shown as a function of distance from the aircraft. The band plot is representative of noise generated by fans optimized for volume, weight, and performance. The single line shows noise intensities which may be realized with the application of all these noise reduction techniques. This curve is an analytical curve and therefore must be somewhat suspect; however, it does give an indication of the potential available. These noise values are competitive with the noise from existing helicopters.

Some unusual work is being do[illegible] that may be applicable to helicopter rotors, propellers, or ducted fans. It was brought to our attention

that owls fly very quietly. It was postulated that one f the reasons for the low noise level was a unique feather on the wing leading edge. This feather appears to have vortex generators along the leading edge. Figure No. 7 is a sketch of the feather leading edge. For our experiment, the leading edge was modeled out of sheet metal and put o.. a model propeller mounted as shown on Figure No. 7. Figure No. 8 shows sound pressure level as a function of the model thrust. For a given thrust level, the owl leading edge reduced noise four to eight decibels. Since measurements were not complete in this investigation, the effect of the owl leading edge on propeller efficiency is not known. Figure No. 9 shows sound pressure level versus frequency with and without the owl leading edge. The owl leading edge reduced the noise above 250 hertz. It would be logical to assume that the owl leading edge worked mainly on vortex noise. However, the noise reductions seemed to be too large to have been a vortex noise reduction. The mechanisms of this noise reduction are not understood and are currently a subject of additional study. It is not known whether this noise reduction will disappear with increased blade loading or blade tip Mach number.

Recent noise reduction work on rotary wing aircraft shows promise. Figure No. 10 presents the effect of a tip modification on noise. This work was done by Sikorsky Aircraft. By changing the tip from a rectangular tip to a trapezoidal planform, noise was reduced by over 5 dB. This is probably a result of weakening of the tip vortex. Bell Helicopter has run an experiment on a rotor with a reduced thickness tip. Here, the rotor airfoil section was varied from a standard 0012 section at .8 radius to an airfoil resembling a 64-206 airfoil at the tip. The effect of this modification is shown in Figure 11. Sound pressure level versus advancing tip Mach number is shown. The blade with the thin tip had noise levels 3 dB below the standard tip throughout the Mach number range. These results encourage further research on reducing rotor noise through tip modifications. It is difficult to envision elimination of rotary wing blade slap caused by tip vortex cutting. However, it should be possible to define operational envelopes which would minimize the occurrence of this noise. Such an operational envelope is sketched in Figure No. 12. Rate of climb is shown as a function of air speed. On the left side of the curve is the compressibility boundary which would correspond to .8 advancing tip Mach number. The envelope at low speed and with small rate of descent is the tip vortex cutting boundary. While these actual boundaries would be a function of parameters such as disc loading and number of blades, it should be possible to define operational limits for a particular rotor. Control inputs can change operational limits but adherence to an operating envelope should greatly reduce the occurrence of blade slap.

It has been shown that there are a number of ways to significantly reduce the noise of power plants. The overall value of this noise reduction, however, must await complete systems analysis to determine the effect on airplane performance, weight, and operating economics.

DOMINANT NOISE SOURCES OF FANS

- STAGE INTERACTIONS
- ROTATIONAL
- JET MIXING
- VORTEX

Figure No. 1

EFFECT OF ROTOR-STATOR SPACING

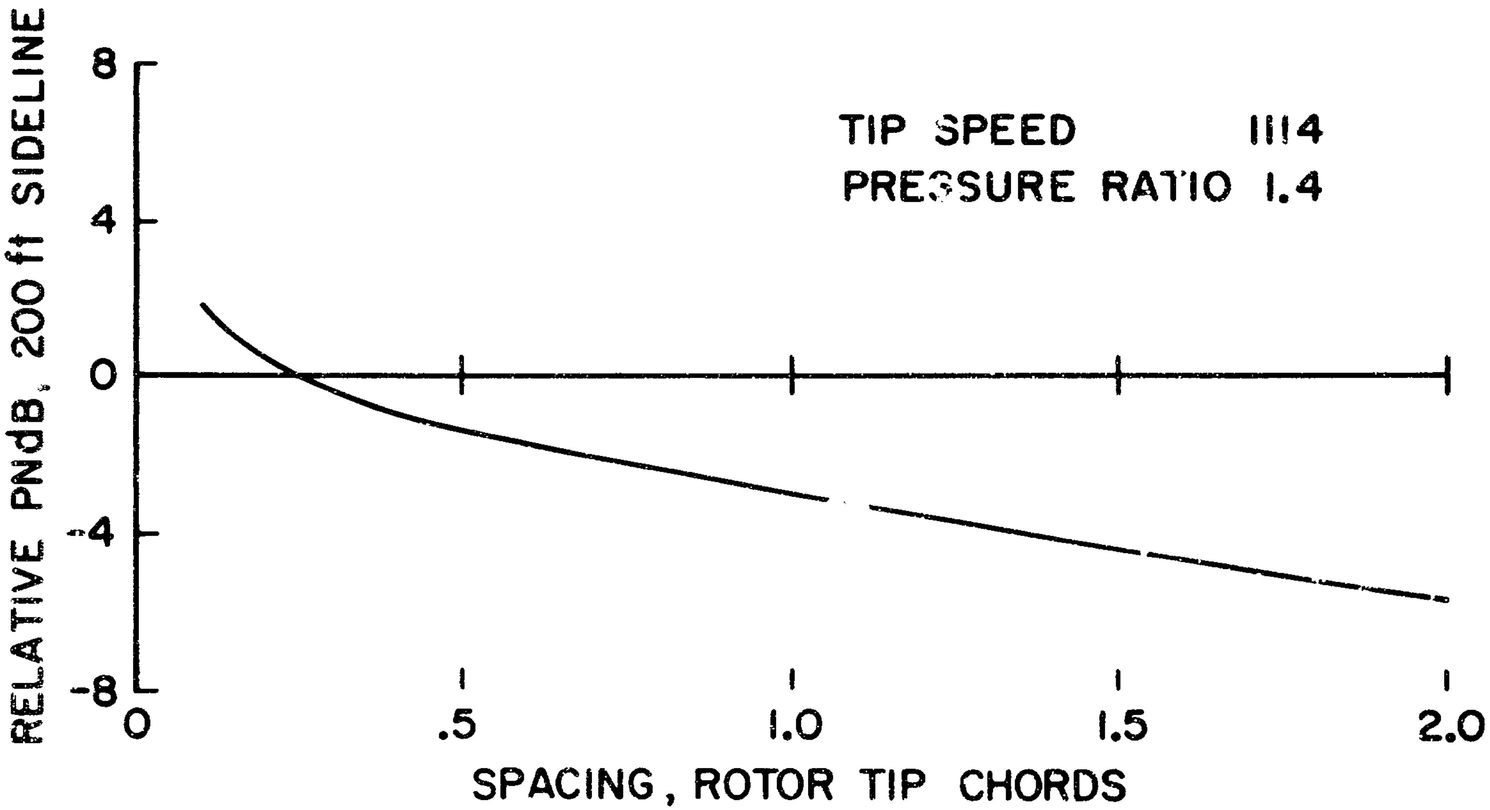

Figure No. 2

PERCEIVED NOISE LEVELS VS NUMBER OF VANES, DOWNSTREAM STATOR

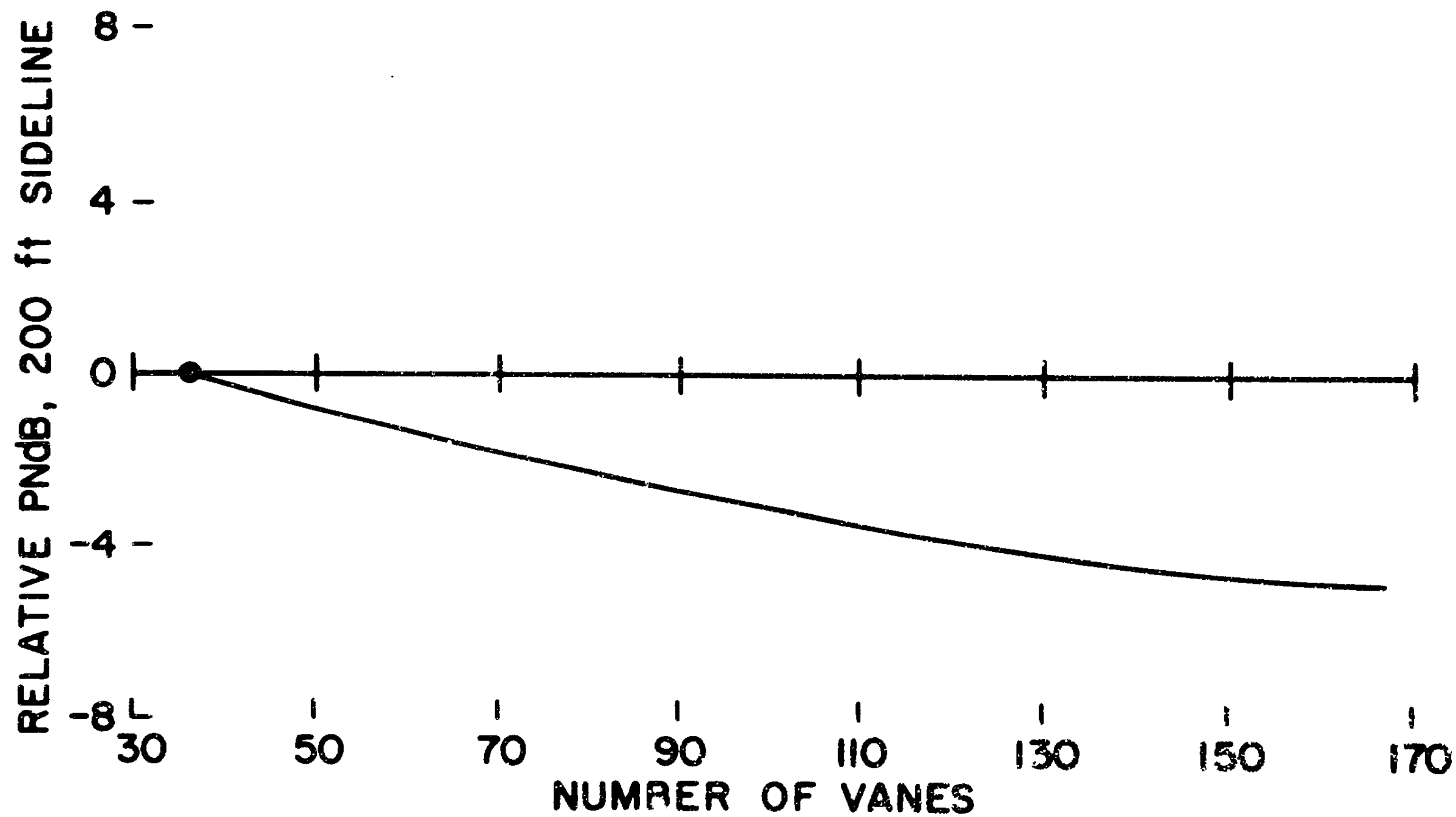

Figure No. 3

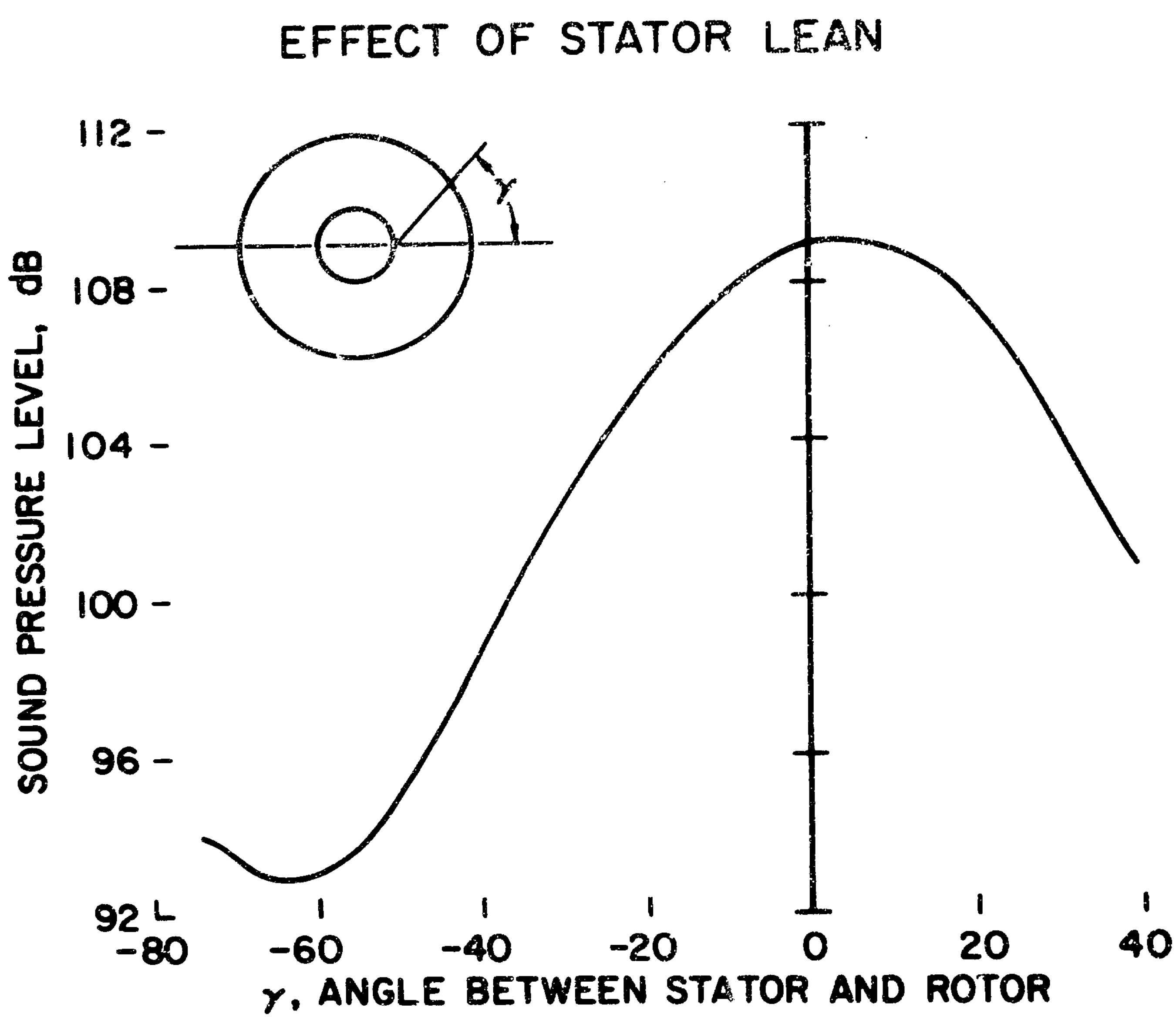
EFFECT OF STATOR LEAN
SOUND PRESSURE LEVEL, dB
112
108
104
100
96
92
-80
-60
-40
-20
0
20
40
γ
γ, ANGLE BETWEEN STATOR AND ROTOR

Figure No. 4

EFFECT OF BLADE NUMBER

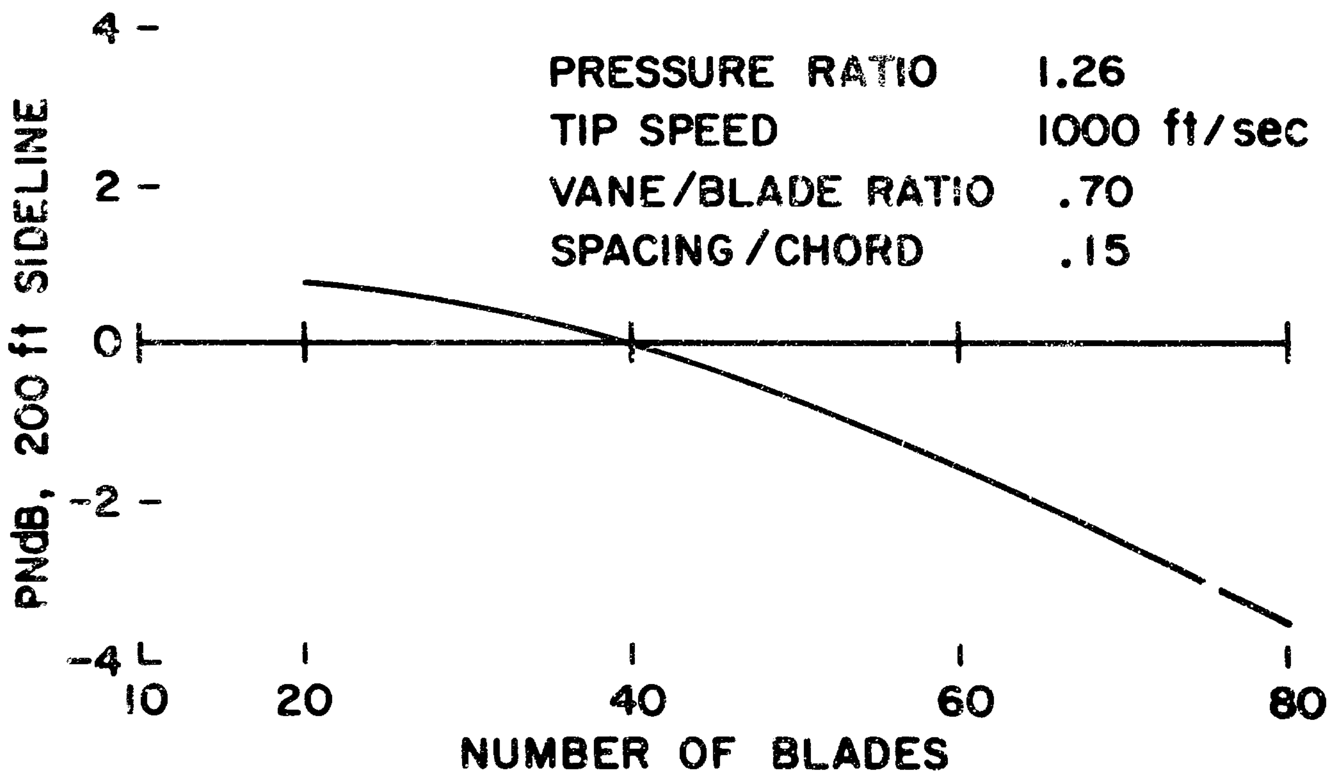

Figure No. 5

LIFT FAN NOISE REDUCTION POTENTIAL
T = 25000 lb

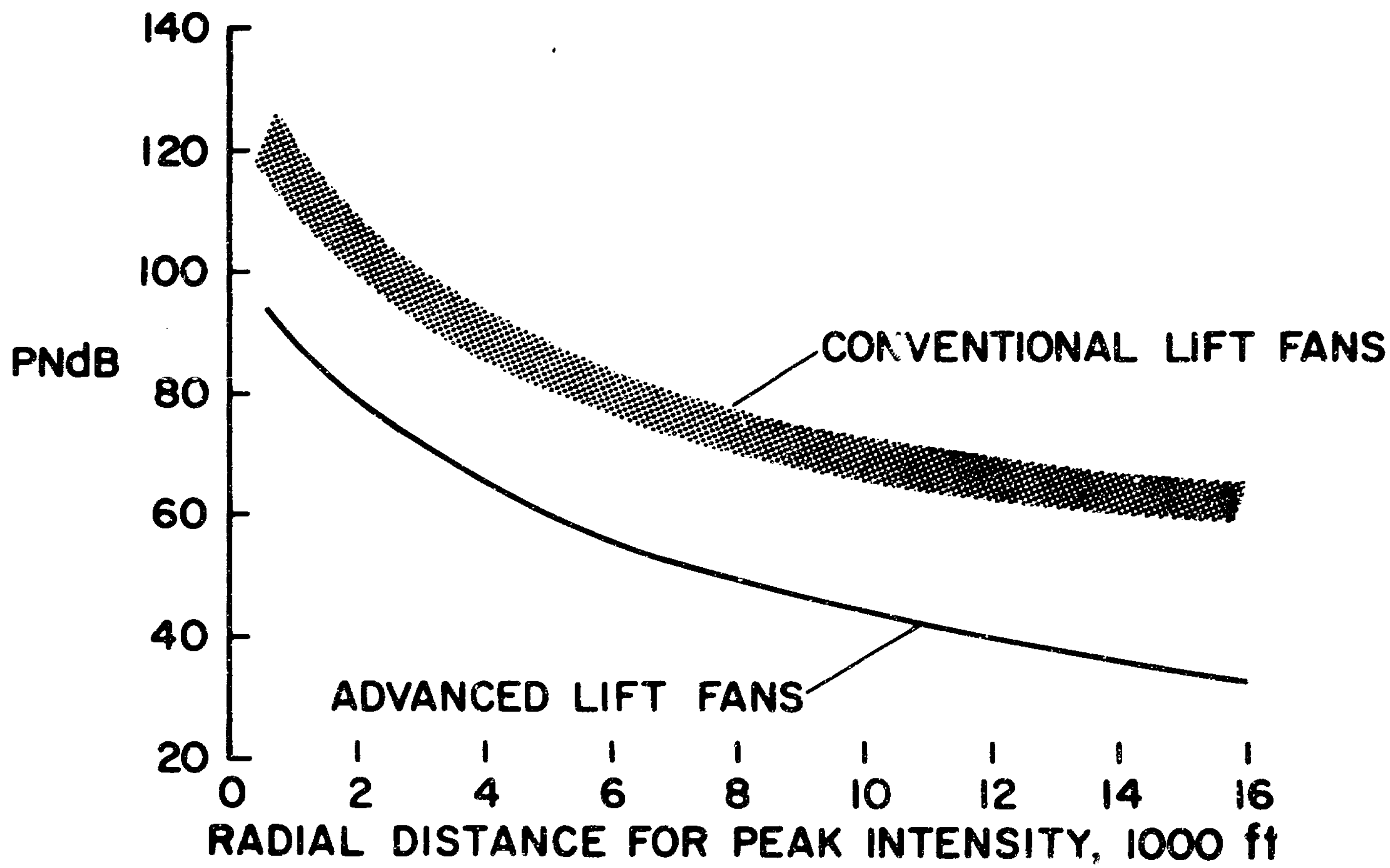

Figure No. 6

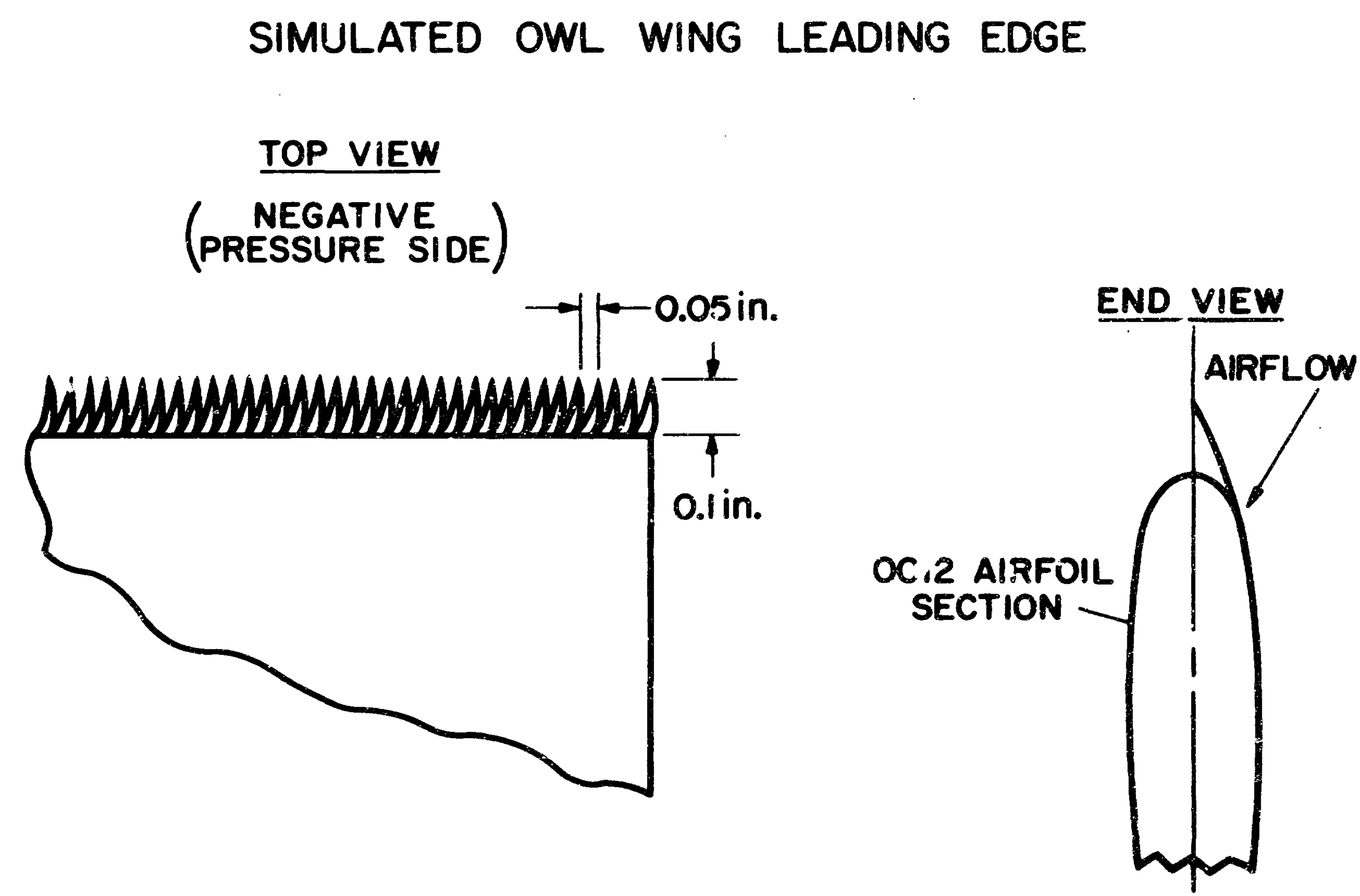
SIMULATED OWL WING LEADING EDGE
TOP VIEW
(NEGATIVE PRESSURE SIDE)
0.05 in.
0.1 in.
END VIEW
AIRFLOW
OC.2 AIRFOIL SECTION

Figure No. 7

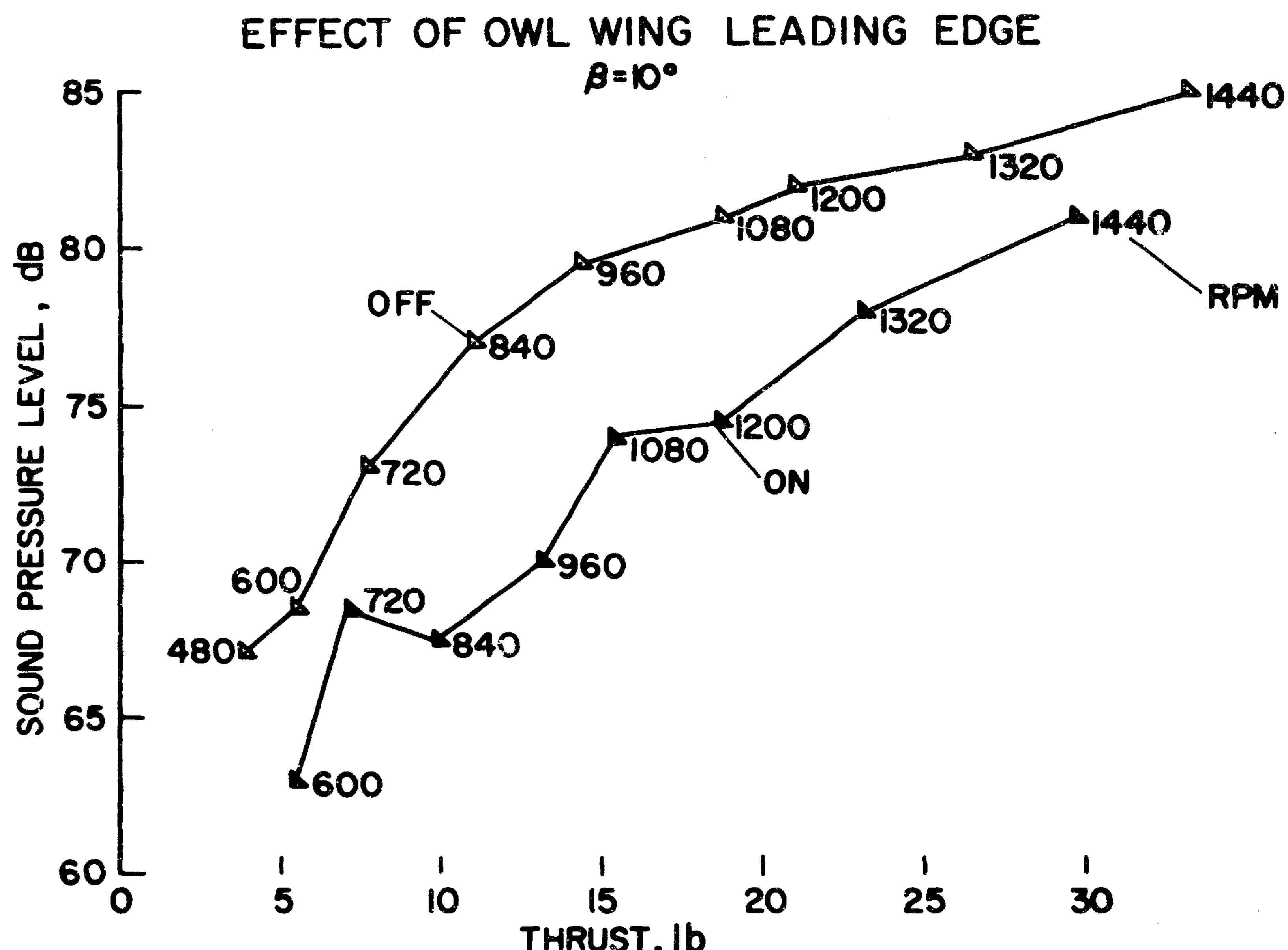

Figure No. 8

AAA 985-18

HICKEY/SODERMAN

EFFECT OF OWL WING LEADING EDGE ON NOISE SPECTRUM

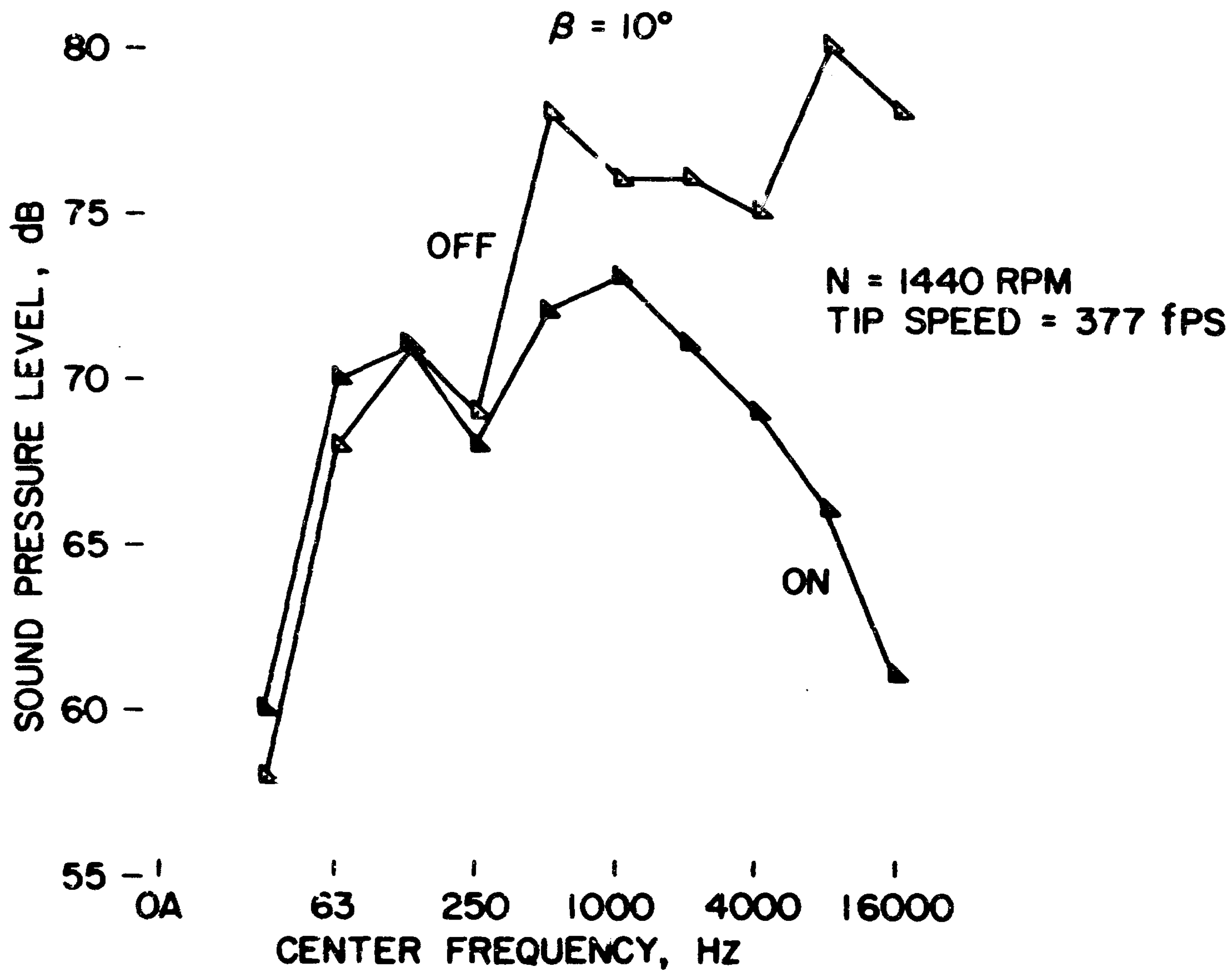

Figure No. 9

EFFECT OF HELICOPTER ROTOR TIP PLANFORM MODIFICATIONS

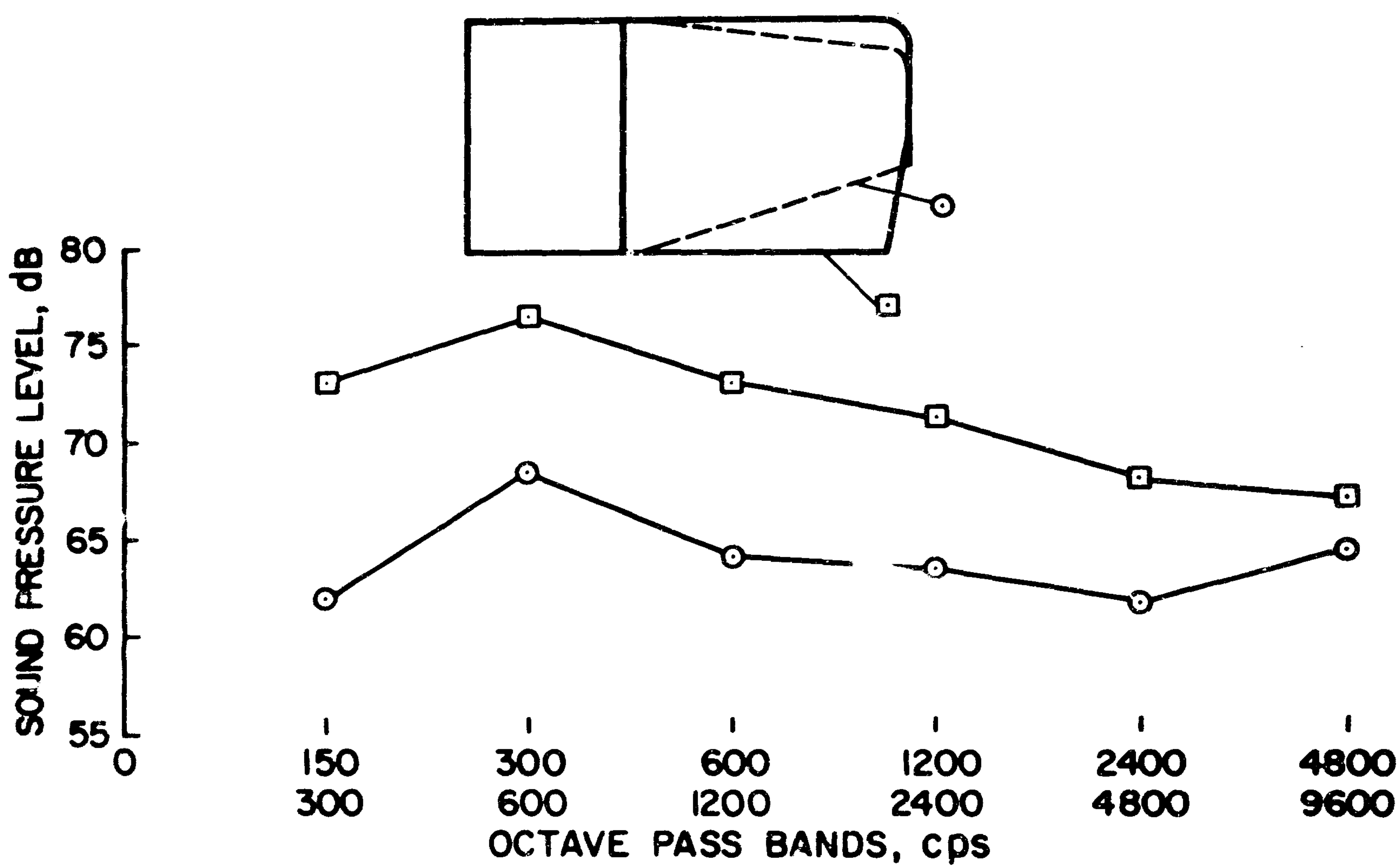

Figure No. 10

HICKEY

COMPARISON OF STANDARD AND THIN-TIPPED ROTOR

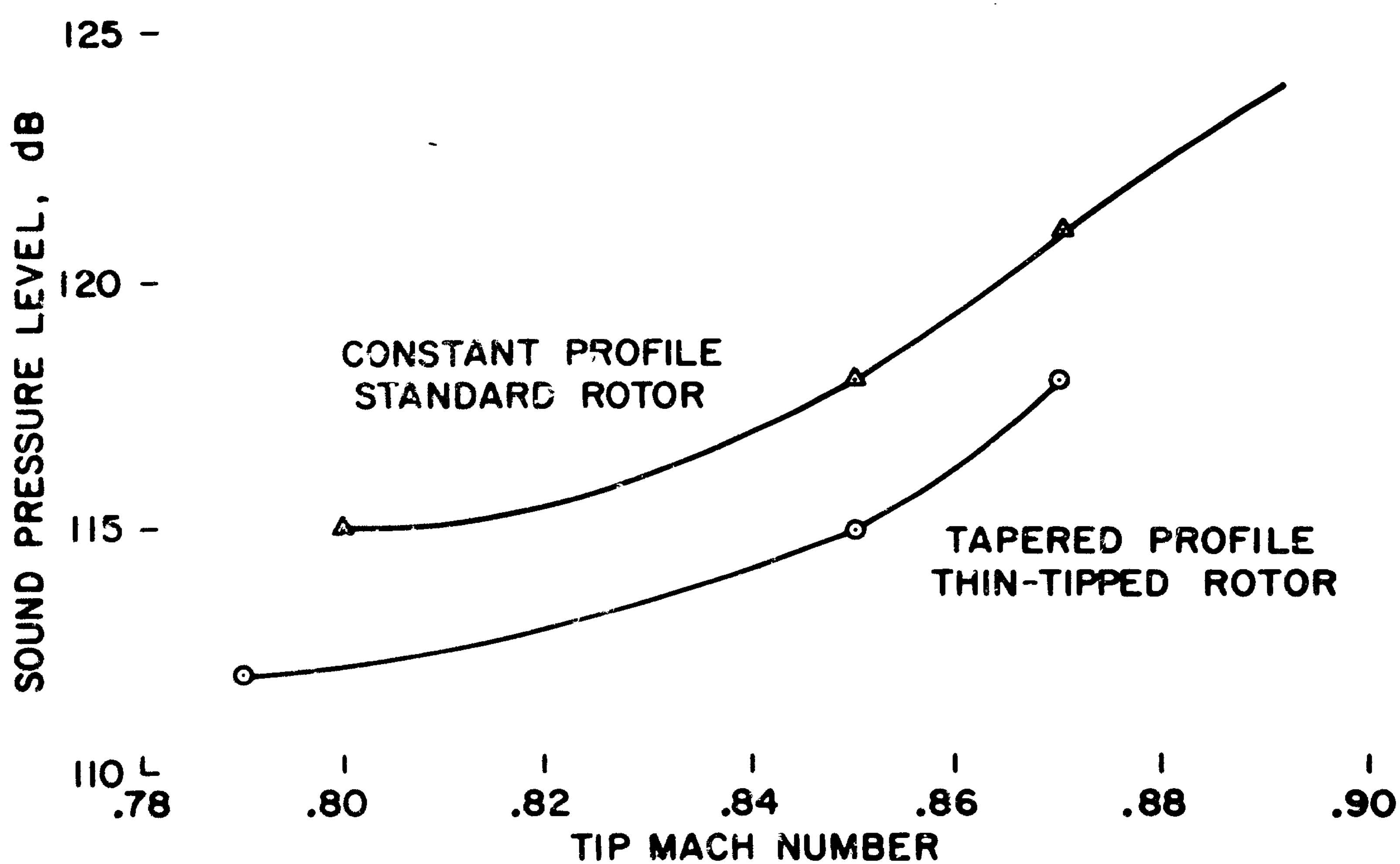

Figure No. 11

OPERATIONAL LIMITS

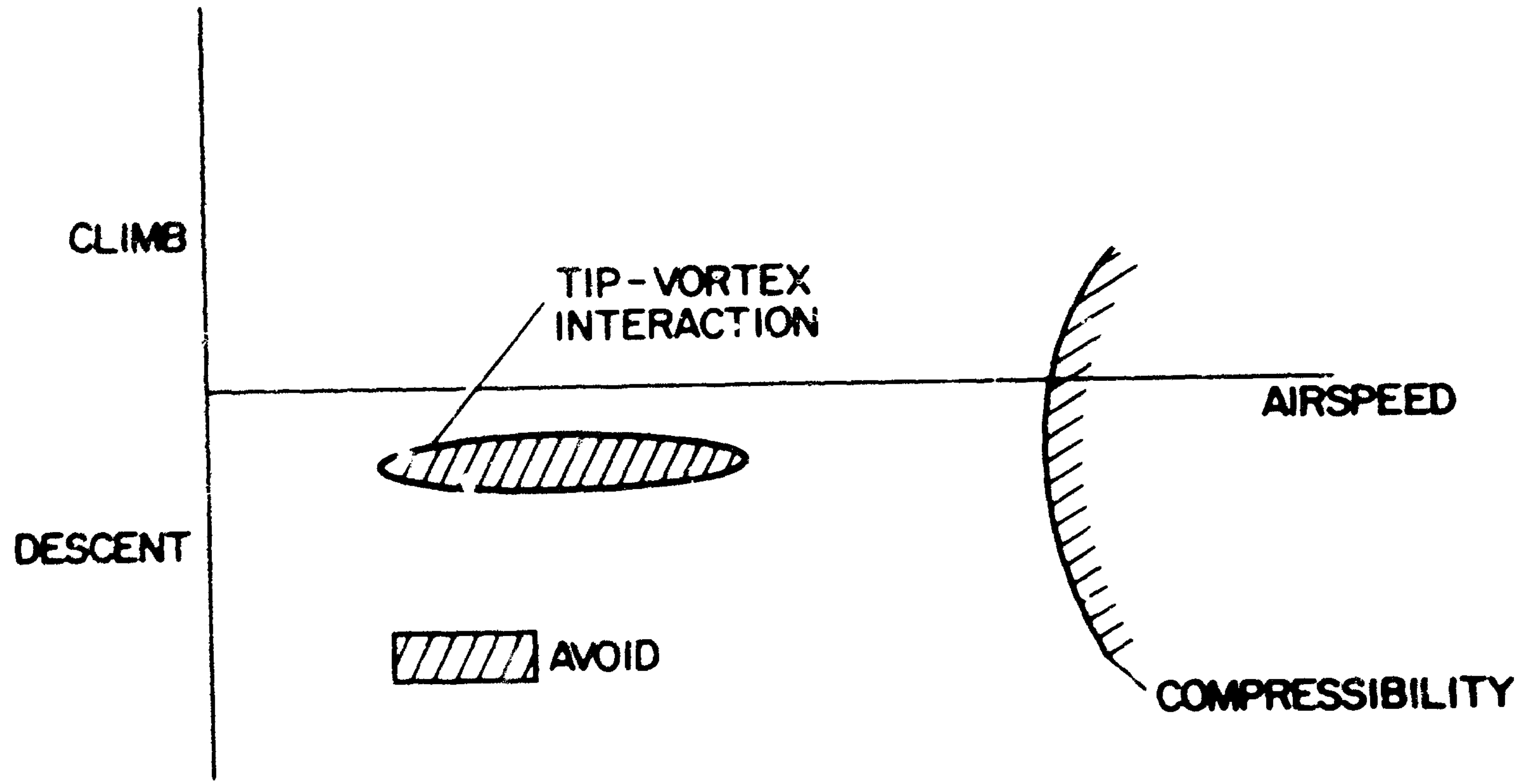

Figure No. 12

HICKEY

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NOISE REDUCTION TECHNIQUES FOR PROPELLERS AND ENGINES

by

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Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

NOISE REDUCTION TECHNIQUES FOR PROPELLERS AND ENGINES

ABSTRACT

This paper summarizes the experience to date in reducing noise from such propulsion devices as reciprocating engines, propellers, and jet engines including both turbojet and turbofan types. Significant factors in noise generation are indicated for each device. The effects of such factors as tip speed, forward speed, and number of blades for propellers; exhaust velocity of jets; and guide vane spacing and inlet and exhaust duct acoustical treatment for fans and compressors are discussed and are illustrated by means of example data figures.

INTRODUCTION

This paper contains a brief summary of noise reduction techniques applicable to some types of STOL aircraft. The particular noise producing components considered in the paper are listed in figure 1. For reciprocating engines, exhaust muffler technology is discussed. For propellers the effects of such parameters as rotational speed, forward speed, and number of blades are considered. For gas turbine engines, both turbojet and turbofan types are considered, and reduction of jet mixing and internally generated noise is included. Particular items included are the effects of internal spacing of components, inlet flow Mach number, nacelle acoustic treatment on rotating machinery noise, and the use of exhaust suppressors and shielding for reduction of jet mixing noise.

RECIPROCATING ENGINE EXHAUSTS

The types of engine exhaust mufflers considered for noise reduction are indicated in the sketches of figure 2 along with sample performance curves. Resonator type mufflers are characterized by a noise reduction curve having a single sharp peak. Such devices are especially useful for eliminating strong narrow-band noise components from the spectrum, and have associated with them relatively small engine performance losses. The expansion chamber muffler is characterized by a relatively flat noise reduction curve. It provides substantial noise reductions over a broad frequency range, however, the performance losses are somewhat larger than those of the resonator type. Both the resonator and expansion chamber mufflers, which are reactive type systems, are most effective at frequencies below about 700 Hz. The most effective device at frequencies above 700 Hz is the dissipative type muffler which incorporates sound absorbing materials. For any particular noise reduction requirement, it is necessary to first acquire measured engine noise spectra and then to select suitable muffler elements based on weight, gas flow, and geometry considerations. This selection process is facilitated by the use of machine computer programs.

PROPELLERS

Propeller noise is a function of several different factors which can be grouped as indicated in figure 3. The main headings are: velocity, which includes both the rotational and forward velocity of the propeller; the propeller geometry, that is, number of blades, diameter, and blade planform; and load considerations which include the inflow patterns, disk loading, blade load distribution, and the instantaneous airfoil section pressure distributions. It is believed that each of these factors may in some cases be very significant. For purposes of illustration the effects of only three of these will be included and are indicated by the asterisks.

Tip speed and blade number - The effects of tip speed and number of blades are shown by the data of figure 4 where the relative overall noise levels are plotted as a function of tip speed for propellers of the same diameter having three, four, six, and eight blades absorbing the same horsepower. The solid curves of figure 4 represent the low frequency (rotational) noises. The dashed curve on the other hand represents the high frequency (vortex) noises. These calculated curves, which are supported by experiments, indicate that lower noise levels are associated with lower propeller tip speeds or a larger number of blades, or both. The control of the high frequency noises of a propeller, particularly for subjective response, is currently not well understood although there are indications that details of the geometry and the instantaneous pressure distributions on the blades can be significant. It remains for additional studies to be performed before direct approaches to high frequency noise reduction can be formulated.

Forward speed - Of particular significance for STOL operations are the effects of aircraft forward speed. These effects are illustrated by the data of figure 5 which show the relative noise levels of a propeller in flight at various forward speeds. The data relate to a rotational Mach number condition of about 0.7. It can be seen that at low forward velocities the radiated noise levels tend to be lower than but are not markedly different than those for the zero forward speed condition. At higher forward speeds, however, there is a very rapid increase in noise levels as a function of forward speed. The conditions at which this rapid increase occurs are those for which the resultant tip speed of the propeller becomes sonic. It should be remembered that STOL vehicles inherently have sufficient installed power for high cruise speed capability. It is believed that in order to keep cruise speed noise levels at acceptable values, the propeller rotational tip speeds will have to be restricted.

GAS TURBINE ENGINES

Figure 6 contains a schematic diagram of a fan jet engine and indicates the various sources of noise. Noise generated external to the engine radiates from the region in which the exhaust jet mixes with the ambient air. Noise generated internal to the engine radiates from both the inlet and from the secondary or fan exhaust.

Bypass ratio - The overall noise produced by a gas turbine engine is a function of the bypass ratio. This effect is shown by the data of figure 7. The relative noise levels for a constant thrust level are plotted as a function of bypass ratio, the zero bypass ratio condition representing the turbojet engine. It can be seen that the noise levels associated with the lower boundary on the figure are lower for the higher bypass ratios. This lower boundary is fixed by the jet mixing noise and represents the overall noise reduction potential of the engine. The upper boundary noise levels are associated with the internal noise from the engine. Much current effort is directed toward the reduction of this internally generated noise. A reduction of the internal fan generated noise by means of lower fan tip speeds is the goal of the NASA quiet engine program. In the following figures the results of several other approaches will be illustrated.

Vane-blade axial spacing - The data of figure 8 relate to noise radiated out of the inlet of the compressor and illustrate the effects of spacing between the stationary inlet guide vanes and rotating blades of the first stage rotor. It can be seen that noise reductions are associated with increased axial clearances. Such increased clearances result in changes in the wake structure of the stationary blades and this results in a lessening of the load fluctuations on the rotating blades. The maximum values associated with such increased clearances are of the same order of magnitude as obtained by complete removal of the inlet guide vanes.

Inlet guide vane Mach number - The noise radiated from the inlet can also be affected by the aerodynamic flow velocities in the inlet. The data of figure 9 show noise reductions obtained as inlet Mach number is systematically increased upstream of the compressor. Above Mach numbers of about 0.65 in the inlet guide vane, sizeable noise reductions are observed. Some of these are associated with high subsonic Mach numbers and a dramatic noise reduction results from aerodynamic choking of the flow (at Mach number 1.0 in the inlet guide vane).

Nacelle acoustic treatment - Another approach to the reduction of internally generated noise is the use of acoustic treatments inside the engine. A considerable amount of work has been accomplished in the last few years to develop the particular technology involved with the application of

acoustic treatment. The sketches of figure 10 show schematically the areas of treatment of a JT3D fan engine type power plant for some upcoming flight acoustic evaluation tests. These flight tests represent the climax of a large study effort accomplished mainly by the Douglas and Boeing companies under contract to NASA. Although it is beyond the scope of this paper to discuss the detailed problems of acoustic treatments, it should be pointed out that it has been necessary to develop a special family of materials which have a controlled porosity and yet are able to withstand the erosion effects of high-speed flows inside the engine. Both metallic and nonmetallic materials and a variety of configurations have been found to be useful. Different amounts of noise reduction are expected from the treatments of the two sketches of figure 10. The larger noise reduction is anticipated from the lower configuration which involves the treatment of larger internal areas of the engine.

The anticipated noise reduction for the landing approach power condition of the engine for the bottom configuration is shown in figure 11. The top curve represents the baseline acoustic data for an unmodified engine. The bottom curve is estimated for the modified engine based on ground tests. It can be seen that sizeable noise reductions due to the acoustic treatment modifications are predicted at the higher frequencies. This treatment was designed particularly for the high frequency components associated with the fan section of the engine and which are judged to be particularly annoying.

The duct treatment technology developed to date for conventional aircraft is applicable to vehicles such as STOL's and to power plants other than the JT3D turbofan for which most of the experience is currently available. Although the same physical principles apply, there are problems of prediction of performance of the acoustic materials in these different configurations and environments.

REDUCTION OF JET MIXING NOISE

The noise generated external to the engine in the region of jet mixing is particularly important because it represents a baseline below which it is not profitable to reduce the other noise sources of the engine.

Jet exhaust noise suppressors - Although high bypass ratio engine cycles are useful in reducing this jet mixing noise, there may be situations where greater mixing noise reductions may be required for general acceptance of jet powered STOL vehicles. In this regard the use of jet exhaust noise suppressors has been proposed particularly for use on the lifting engines. Such suppressors have taken the general forms of the schematic illustrations of figure 12 from a recent Boeing study. The ejector family of nozzles incorporates shrouds to induce external flow and to mix it effectively with the primary exhaust flow. The multi-tube suppressor makes use of a large number of small jets rather than one large jet. The decreased jet dimension

leads to a shifting of the frequencies of the noise to much higher values for which the normal atmospheric attenuation losses are much higher. Multi-spoke nozzles are arranged in such a way that external air is ducted through chutes or spokes into the primary jet in order to hasten the mixing process. All of the types of devices represented in figure 12 have produced substantial noise reduction but at the expense of relatively large performance losses. Their usefulness on the primary propulsion unit of the STOL vehicle may be limited because of the complication of additional weight, retraction problems, and aerodynamic losses. Their use on the lift engines, however, may be attractive and the associated weight and performance penalties may be more acceptable than the alternative method of using high bypass ratio engines for lifting.

Jet flap shielding - Another idea that has received only limited consideration up to the present time is the jet flap principle. Its application to a small airplane is illustrated in figure 13. The jet exhaust in each case issues from a slit nozzle located above the wing in such a way that the jet flow attaches to the wing surface. Such a device is capable of increasing the lifting capabilities of the airplane wing and also has the potential of substantial jet noise reduction as indicated in figure 14.

The data of figure 14 represent noise radiation patterns for two different nozzle configurations. Data for the conventional circular nozzle has the characteristic radiation pattern usually associated with jet engines. The dashed line radiation pattern is for a slit nozzle to which is attached a shielding flap which simulates a wing attachment surface. The most obvious result of the shielding flap is the distortion of the noise radiation pattern in a beneficial way. Very little noise is radiated downward and the main lobe of the radiation pattern is directed generally upward. Although there are many practical problems associated with the application of such a concept to STOL aircraft, there is a long range potential for substantial exhaust noise reductions.

Figure 15 is a summary listing of factors appropriate for consideration in jet engine noise reduction. The noise generated internally can be affected by the detailed design of such components as the fan, compressors, and turbines, and through the control of inlet flow Mach number including aerodynamic choking. In addition, the application of acoustic treatments in the inlet and fan discharge ducts as well as in some other critical locations inside the engine, are known to be effective in noise reduction. With regard to the external jet exhaust mixing noise, engine cycle considerations to control the jet velocity, jet exhaust noise suppressors to control mixing patterns, and the concept of jet flap shielding are appropriate considerations.

CONCLUDING REMARKS

In summary of the material presented in this paper, figure 16 is presented. With regard to reciprocating engines, known noise reduction procedures involve external devices such as collector rings, manifolds, and mufflers. Propeller noise reduction technology involves overall design considerations such as number of blades, rotational and forward speed, as well as such detailed design considerations as blade planform, load distribution and airfoil section. In the case of gas turbine engines, useful noise reduction procedures involve specification of the engine cycle, detailed design of its interior stationary and rotating components, and the use of external devices such as acoustic duct treatments and exhaust noise suppressors.

NOISE SOURCES

- RECIPROCATING ENGINES
- PROPELLERS
- GAS TURBINE ENGINES

  TURBOJET

  TURBOFAN

Figure No. 1

MUFFLER CHARACTERISTICS

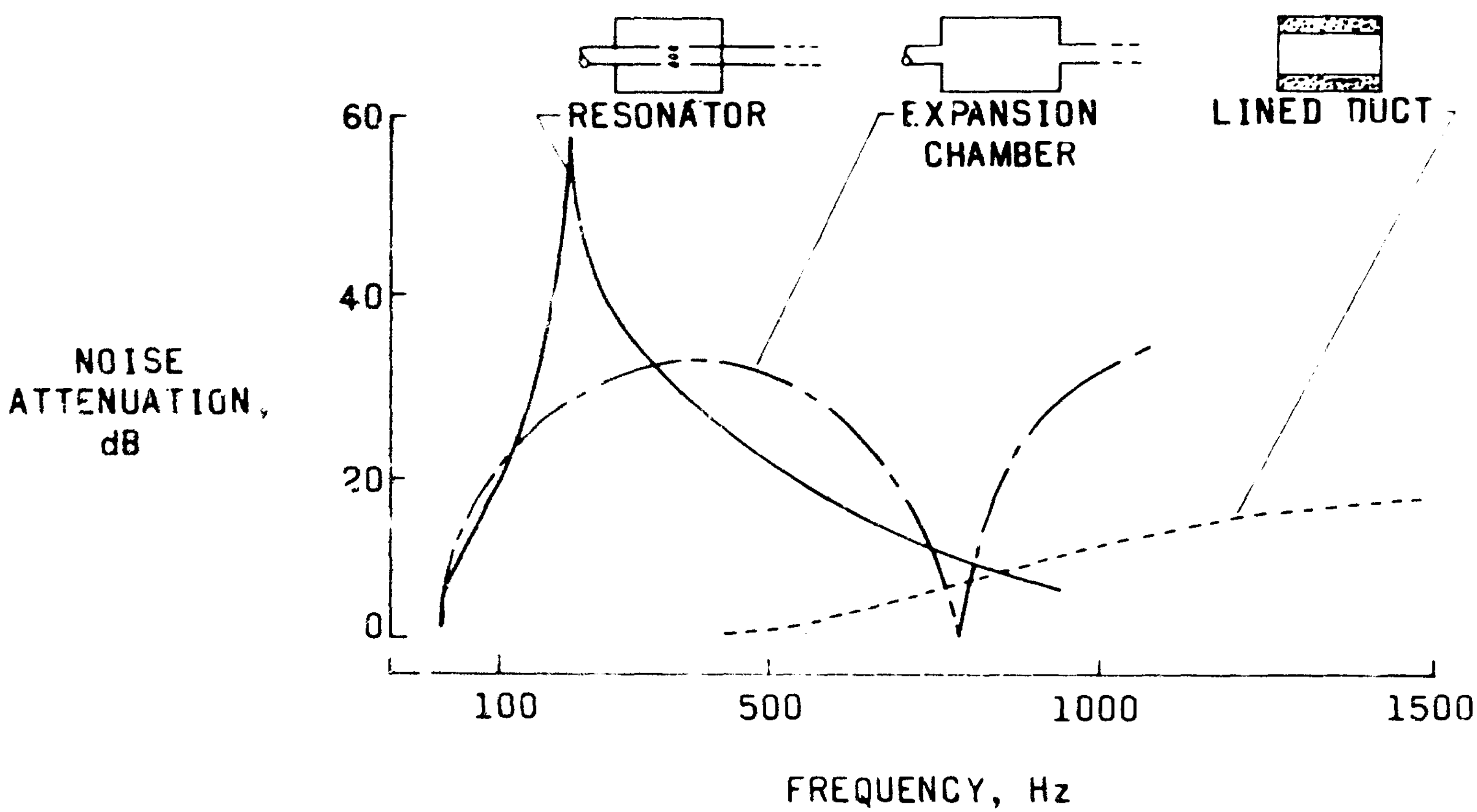


Figure No. 2

PROPELLER NOISE FACTORS

- VELOCITY
  - *ROTATIONAL TIP VELOCITY
  - *AIRPLANE FORWARD VELOCITY
- GEOMETRY
  - *NUMBER OF BLADES
  - DIAMETER
  - PLANFORM
- LOADING
  - INFLOW
  - DISK LOADING
  - BLADE LOAD DISTRIBUTION
  - SECTION PRESSURE DISTRIBUTION

Figure No. 3

PROPELLER NOISE FOR CONSTANT DISK LOADING

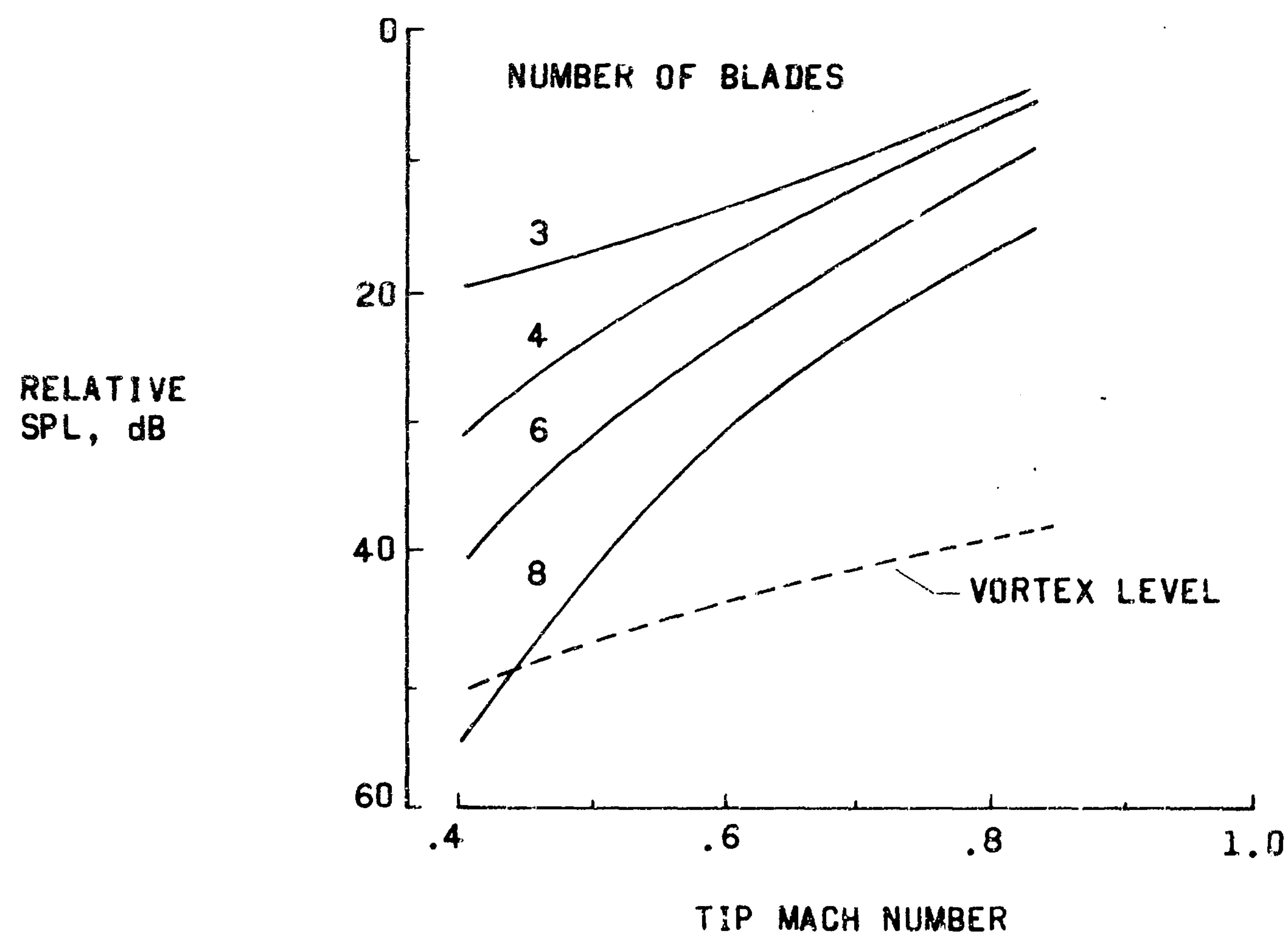


Figure No. 4

EFFECT OF FORWARD SPEED ON PROPELLER NOISE

(M_T = 0.70)

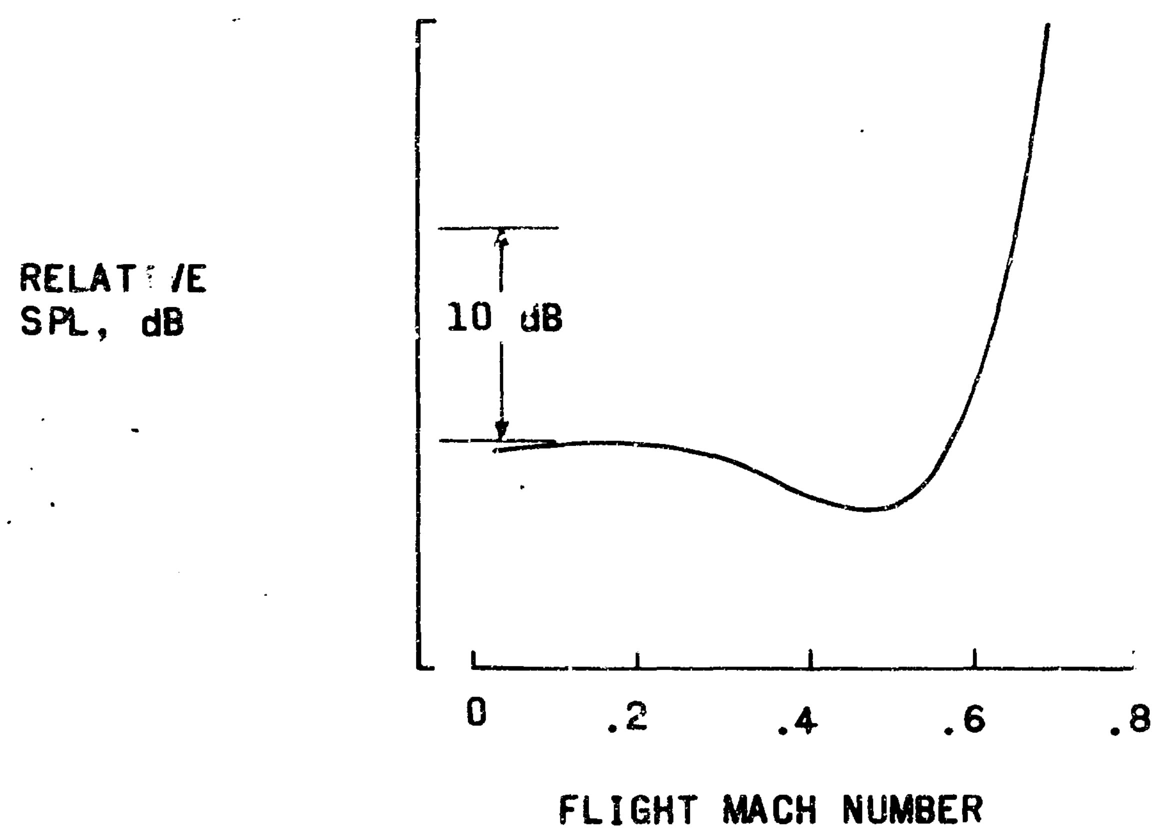


Figure No. 5

TURBOFAN ENGINE NOISE

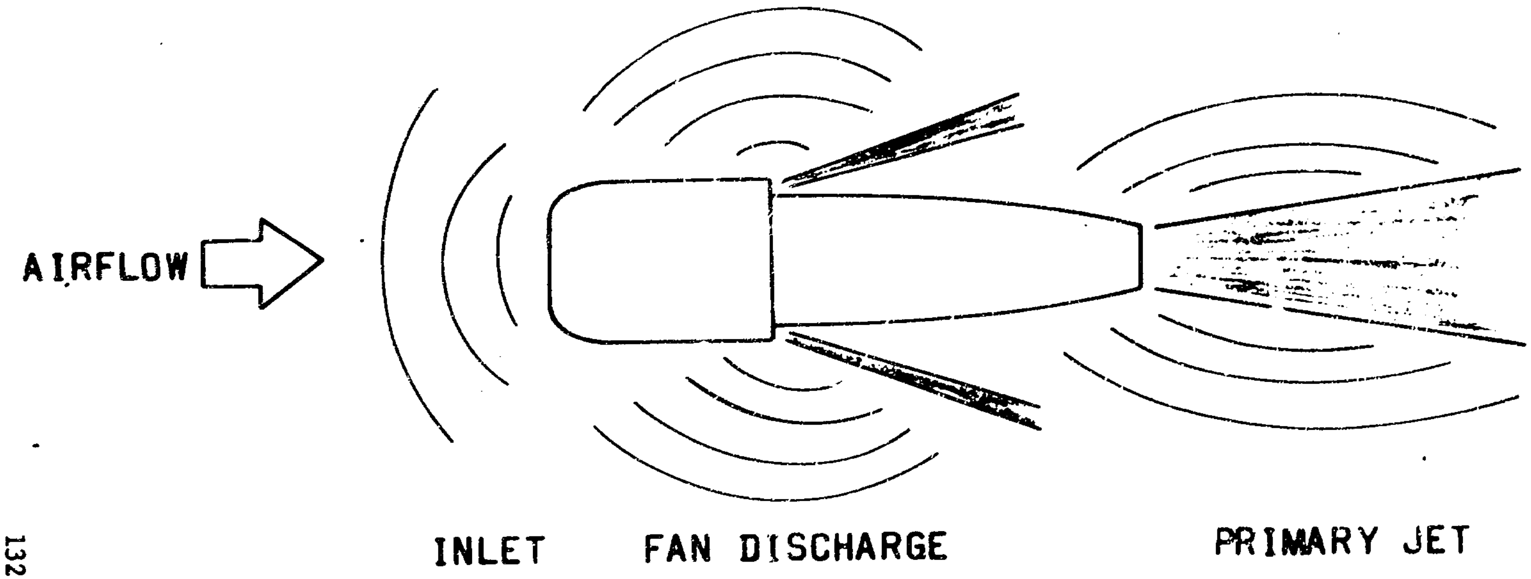
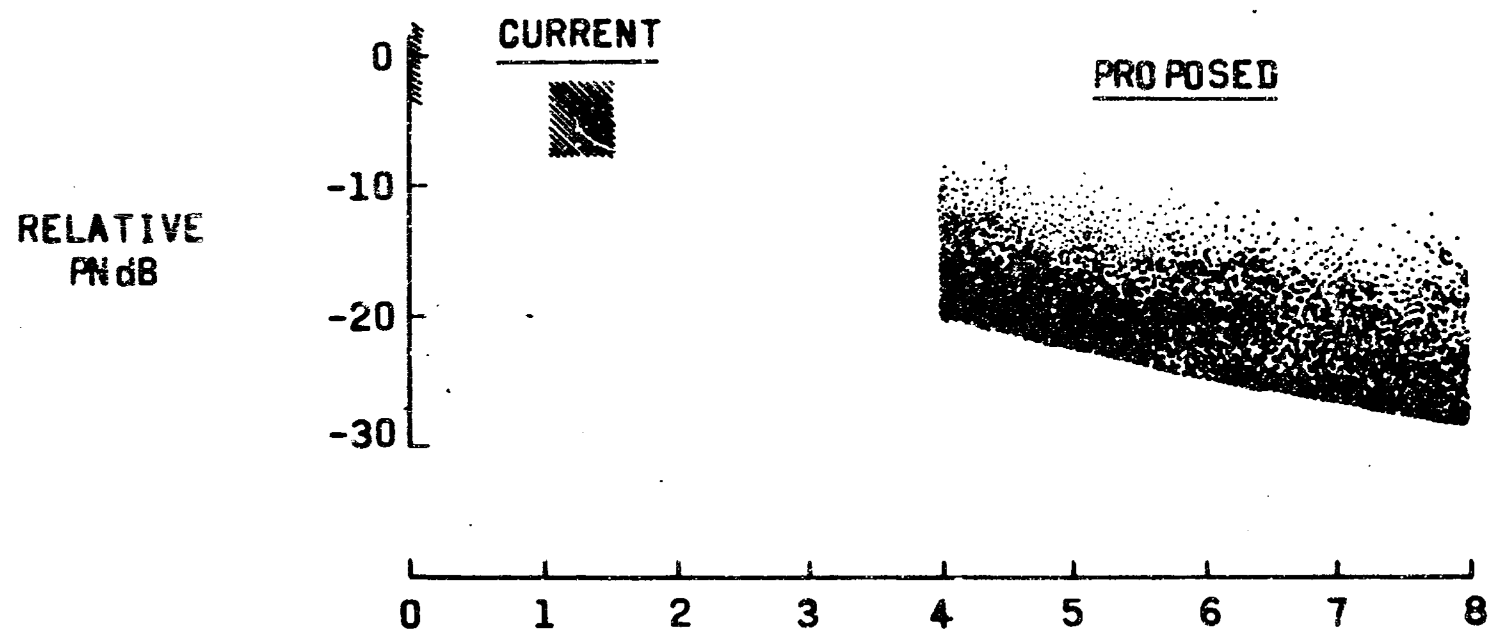


Figure No. 6

EFFECT OF ENGINE BYPASS RATIO



$$\text{BYPASS RATIO} = \frac{\text{SECONDARY FLOW RATE}}{\text{PRIMARY FLOW RATE}}$$

Figure No. 7

EFFECTS OF SPACING

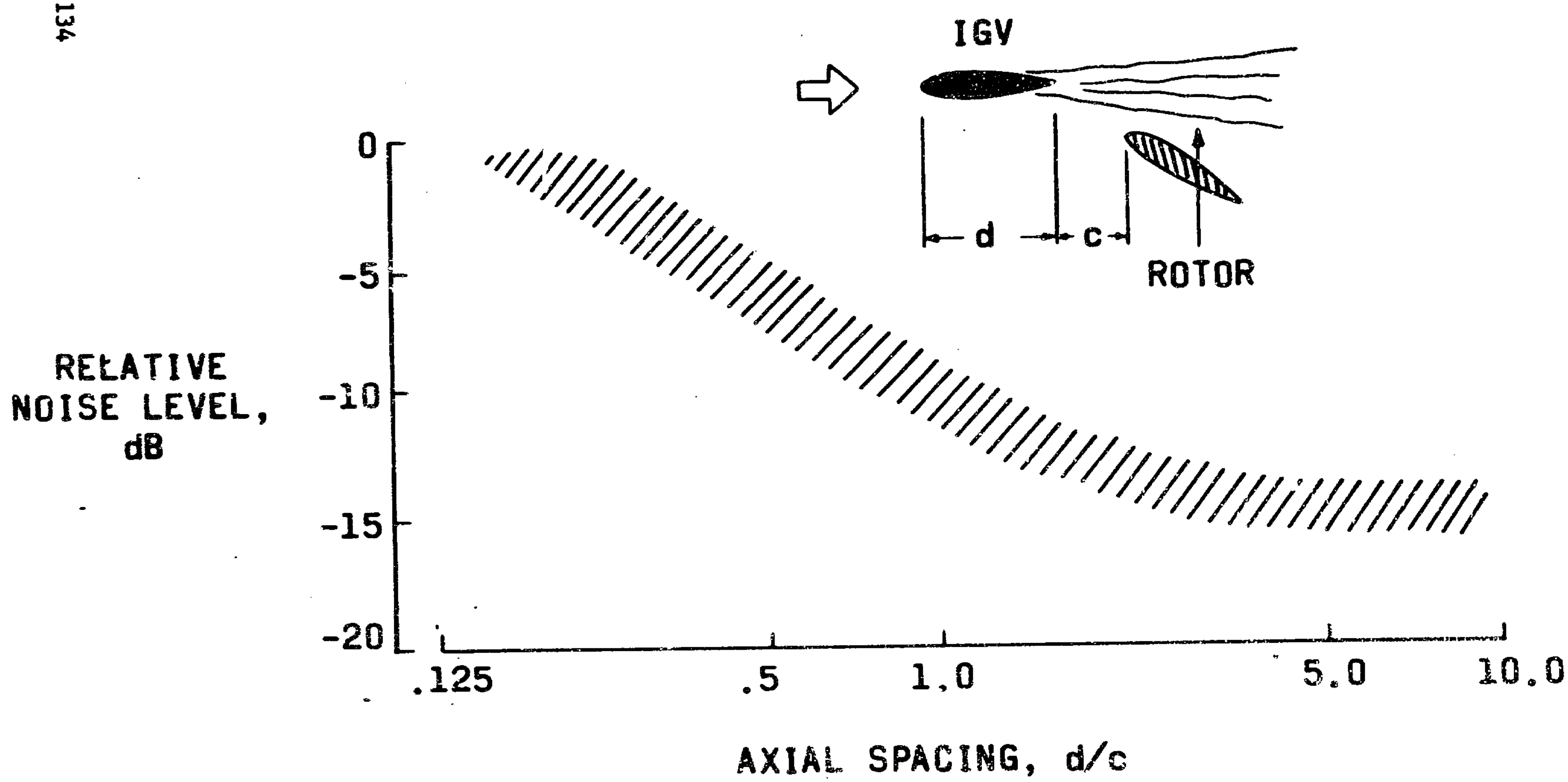


Figure No. 8

EFFECT OF INLET GUIDE VANE MACH NUMBER

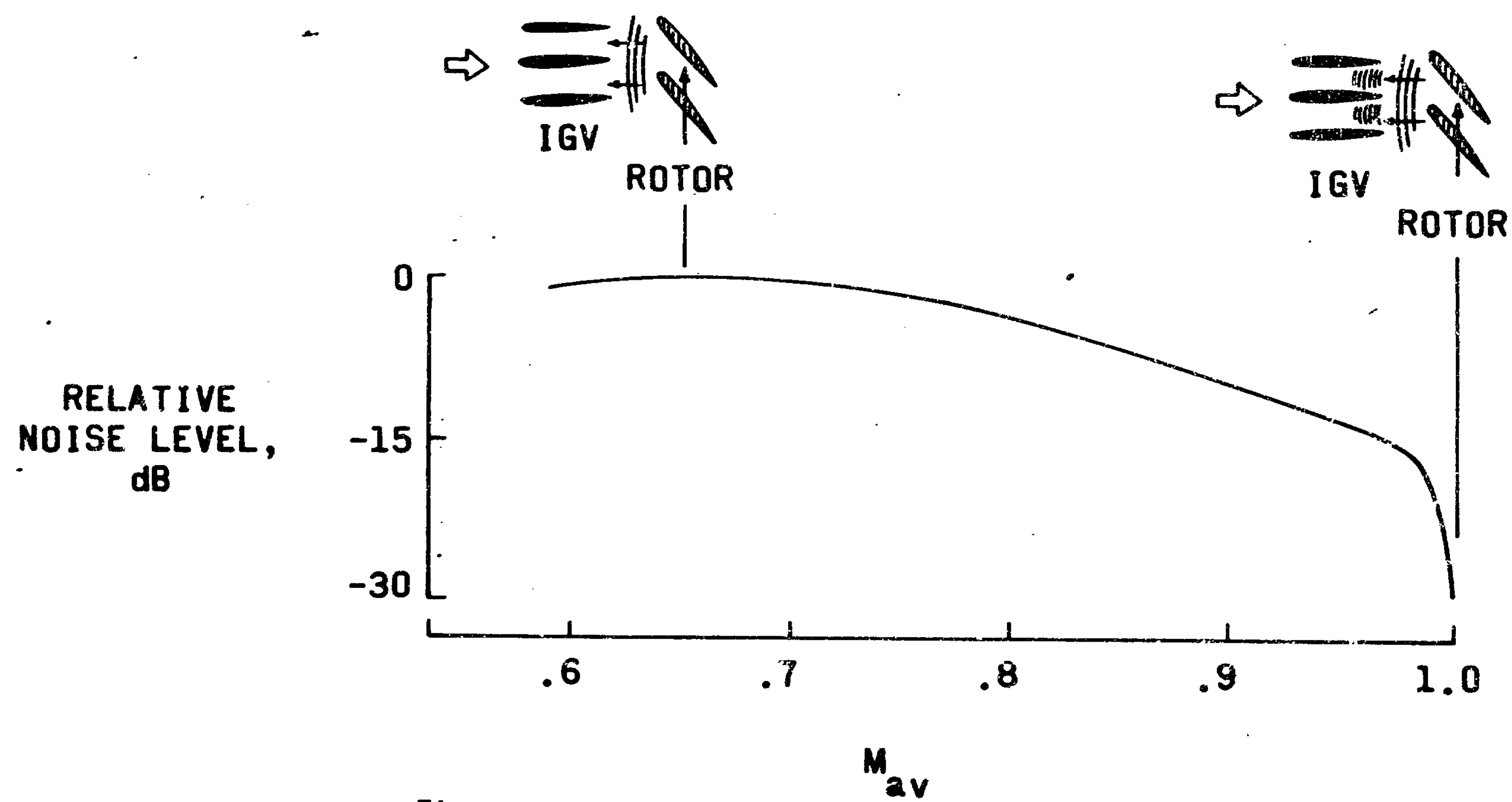


Figure No. 9

NACELLE TREATMENT CONFIGURATIONS

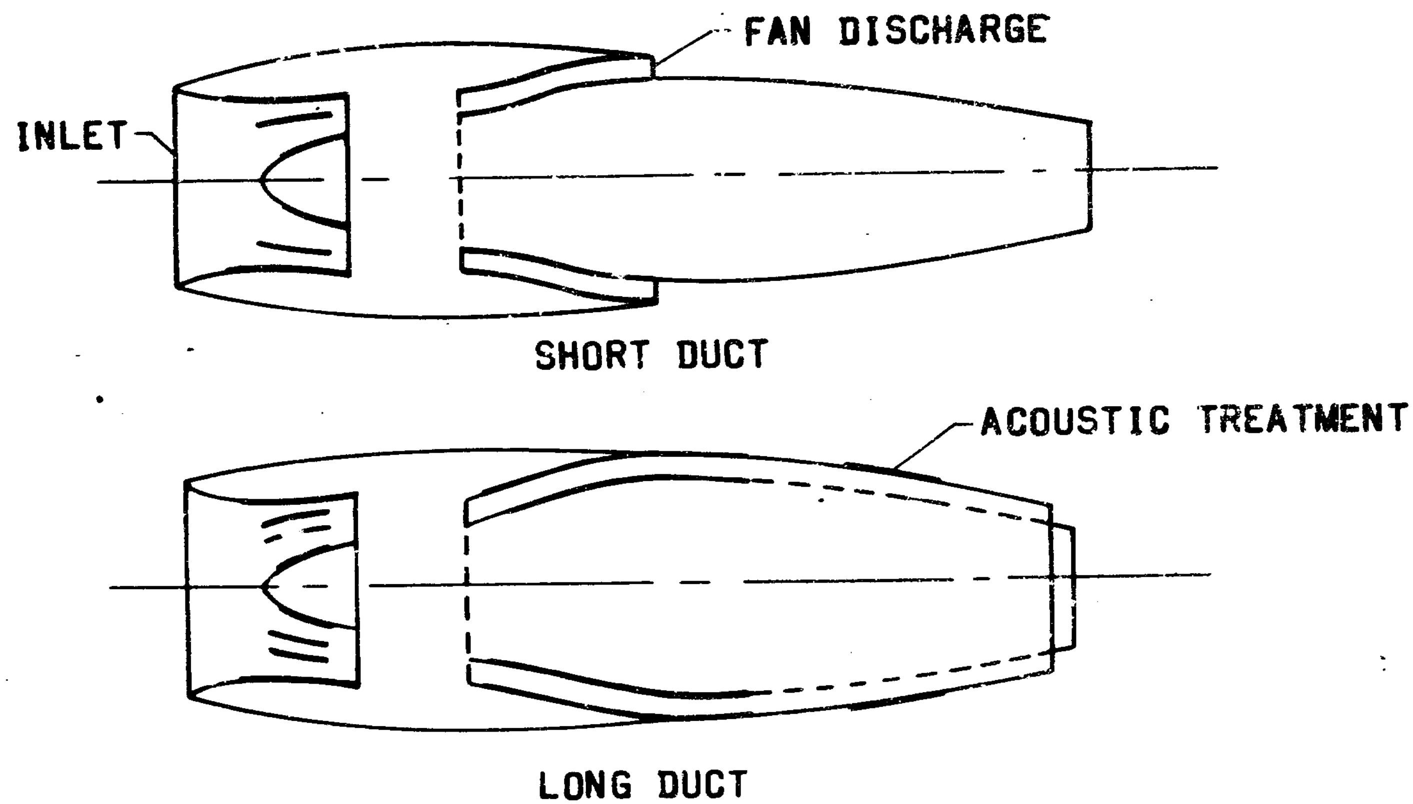


Figure No. 1ǔ

EFFECT OF NACELLE ACOUSTIC TREATMENT

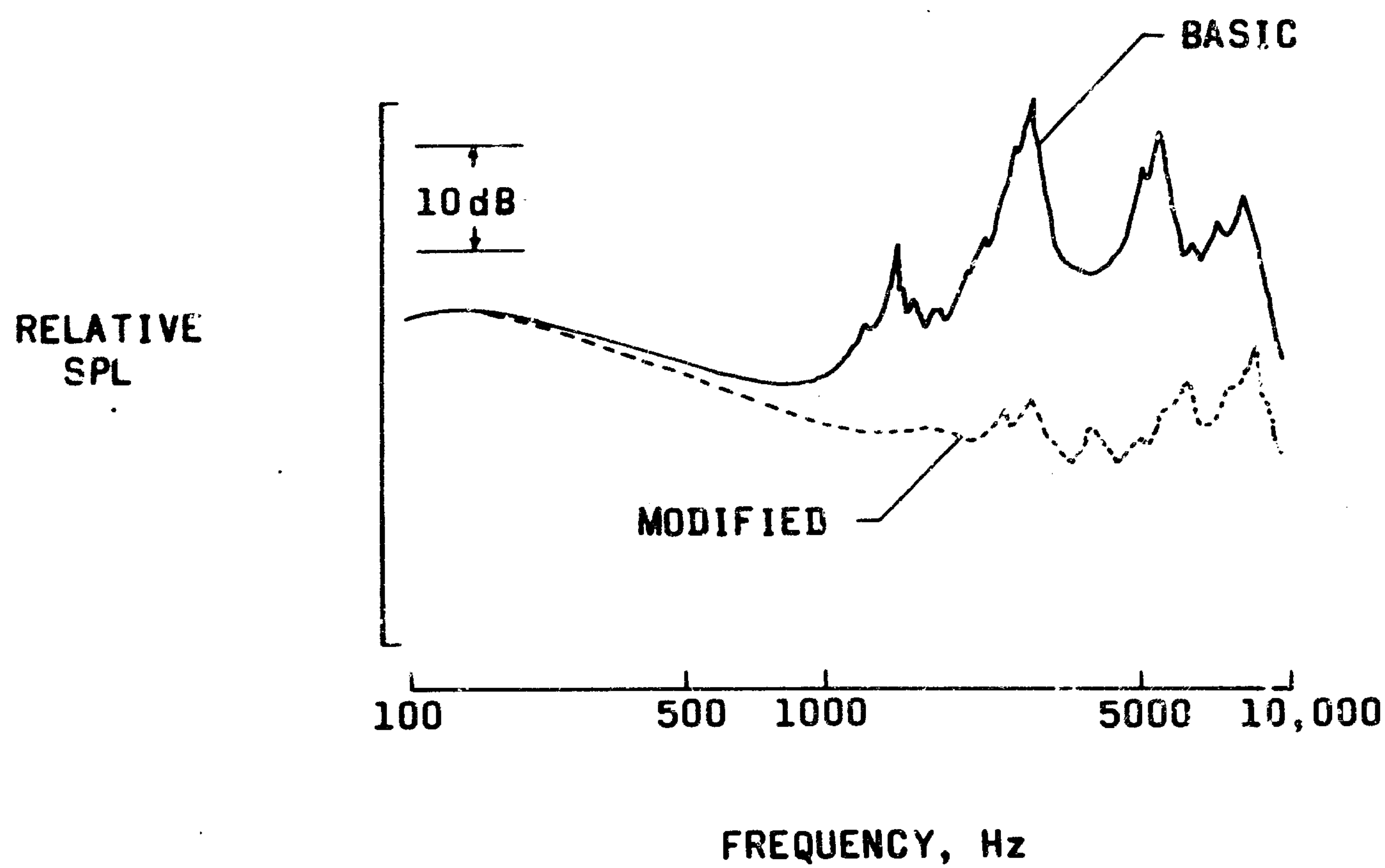
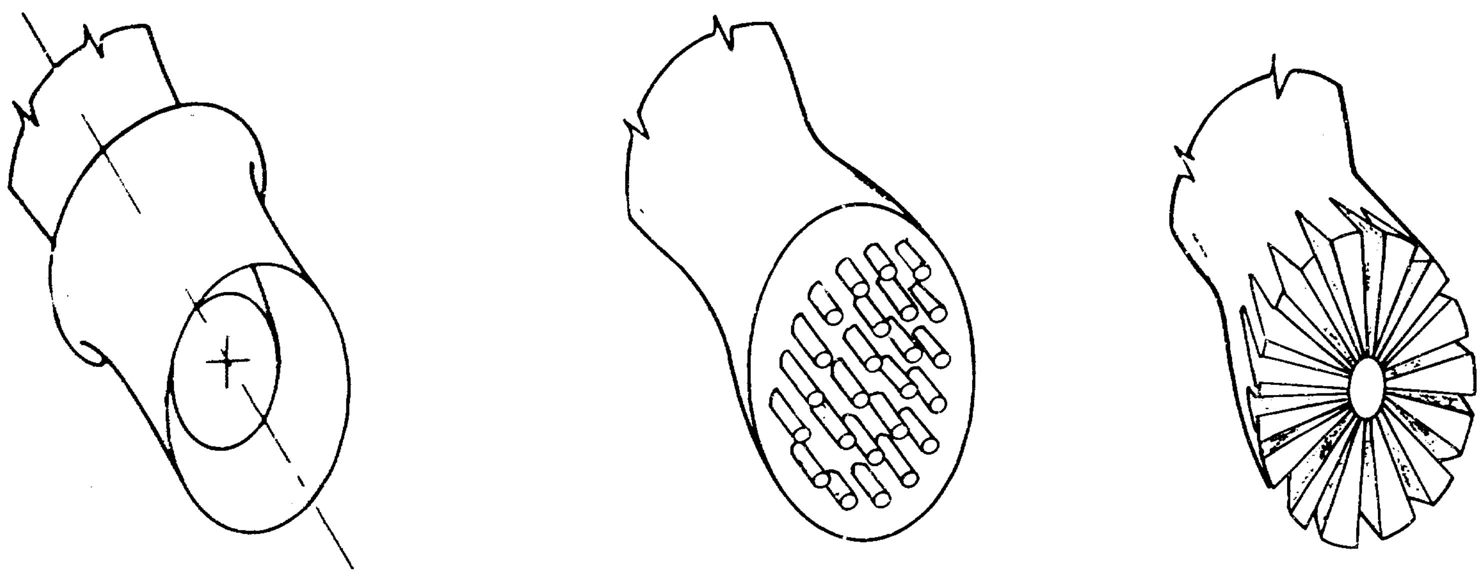


Figure No. 11

JET EXHAUST NOISE SUPPRESSORS



SHROUD
OR
EJECTOR

MULTI-TUBE

MULTI-SPOKE

Figure No. 12

JET FLAP AIRPLANE

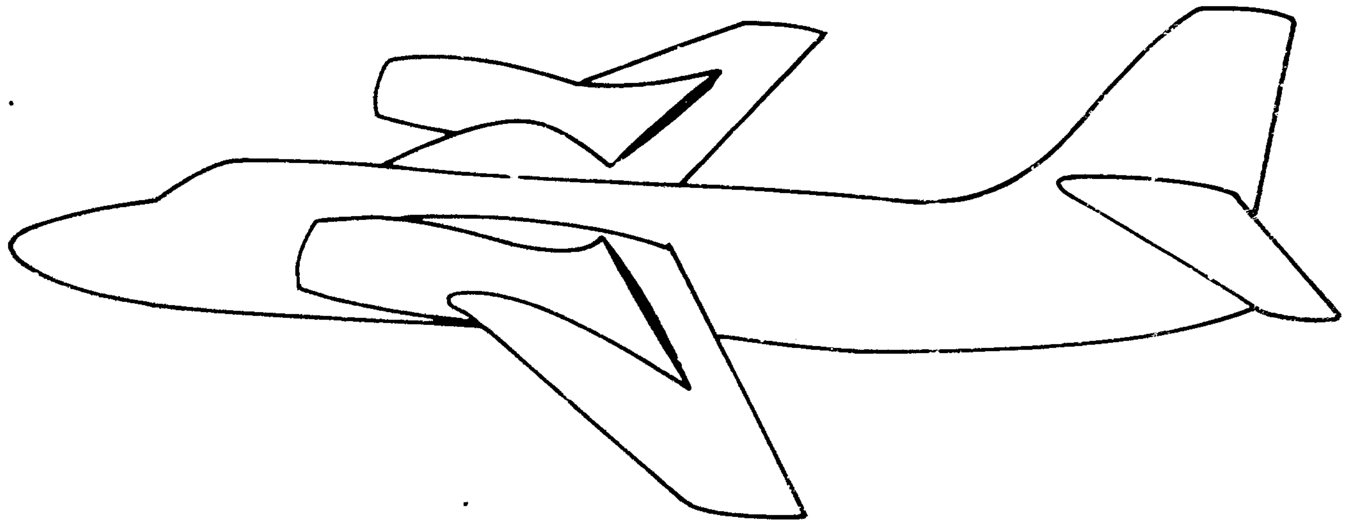


Figure No. 13

JET FLAP NOISE

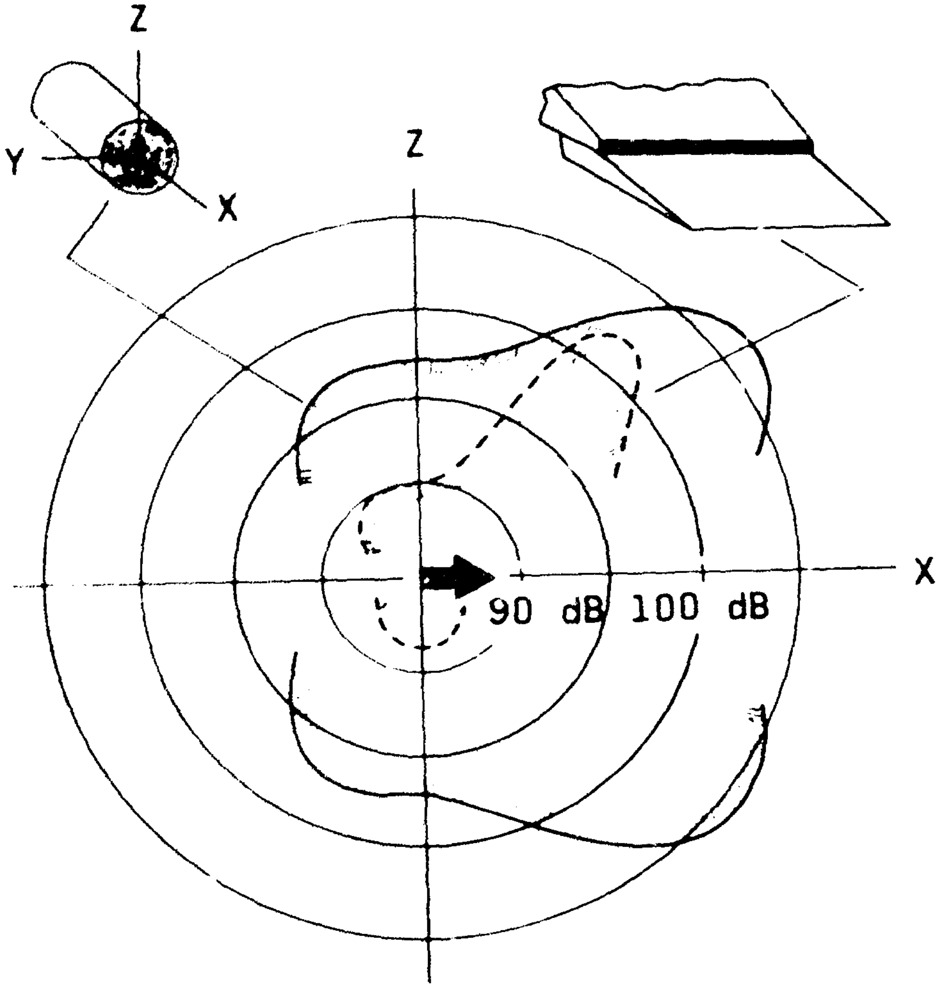


Figure No. 14

JET ENGINE NOISE REDUCTION FACTORS

- INTERNAL FLOW NOISE
  - DETAIL COMPONENT DESIGN
  - INLET FLOW CONSIDERATIONS
  - ACOUSTIC TREATMENT
- JET EXHAUST MIXING NOISE
  - ENGINE CYCLE CONSIDERATIONS
  - SUPPRESSORS
  - SHIELDING

Figure No. 15

NOISE REDUCTION APPROACHES

SOURCE	OVERALL DESIGN	COMPONENT DESIGN	EXTERNAL DEVICES
RECIPROCATING ENGINES			✓
PROPELLERS	✓	✓	
GAS TURBINES	✓	✓	✓

Figure No. 16

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SOME ECONOMIC ASPECTS OF THE AIRCRAFT NOISE PROBLEM

BY

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Delivered Before The Industry/Government Symposium
On STOL Transport Noise Certification In
Washington, D.C.

January 30, 196[illegible]

SOME ECONOMIC ASPECTS OF THE AIRCRAFT NOISE PROBLEM

Introduction

Anyone wishing to study the problem of aircraft noise near airports will not want for reading material. Published reports, papers, and statements amply describe the technical and legal aspects of aircraft noise, the viewpoints of the groups in conflict, and the substantial efforts to date by government and industry to alleviate the noise. Surprisingly, there is little written material to be found dealing with the economic aspects of the noise problem. Perhaps this is the case because noise, in most instances, constitutes a social cost to society -- and social costs do not readily lend themselves to quantification, at least in terms of those economic indicators we most often employ: dollars and cents.

We do know that, over the last decade, there has been an increasing number of people complaining about noise in the vicinity of airports. This has been brought about because jet aircraft are, in fact, noisy; frequency of operations have steadily increased; and, urban encroachment around airports continues at a fairly rapid pace. If the noise factor is not considered during the early stages of development, STOL operations can anticipate even greater public reaction since their viability depends to a large extent in locating STOL ports in close proximity to urbanized areas.

Our legislators, being particularly sensitive to the complaints of constituents, have demanded positive and specific government intervention. But economists, sensitive as they are to social problems, tend to be a skeptical breed -- they know that complaining is cheap and people have a strong incentive to complain whether or not they are unjustly damaged and deserve compensation if they think complaining will change something to their benefit. Believe it or not, some Federal Government economists still believe the market mechanism does a pretty good job of automatically compensating for inequities or imbalances through the pricing system -- and they are hesitant to recommend artificial market manipulation (regulation, if you will) without strong justification. As such, the economist must raise the question: Is there an economic basis for federal intervention in the noise problem; and, if so, what economic objectives and criteria are appropriate for guiding governmental policies regarding aircraft noise?

In light of the lack of literature on the subject, I thought it may be of interest to describe, in general terms, the economic nature of the noise problem; the economic objectives of federal intervention; economic criteria for establishing appropriate levels of regulation; and finally, the rationale employed for determining who should pay for noise alleviation programs. It is hoped that the subject matter will add perspective to a particular type of noise regulation -- aircraft noise certification.

Noise Described As A Cost

It is helpful when speaking of the cost of noise (as distinct from the costs to alleviate noise) to understand how that cost occurs. In this regard, Dr. Kryter, the noted psychoacoustician, has reported, in part, as follows:

> "Numerous laboratory and industrial studies have been conducted in attempts to show that noise has an adverse effect on physical and mental work performance. By and large, the results of these studies show that noise per se probably has little or no adverse effect upon performance provided the work does not involve or require auditory communications of some sort. These results were found even in noise environments where the levels were such that, if continued for several years, ... some permanent damage or deafness would be inflicted upon those exposed to the noise."

These findings indicate that noise is not a component of the typical production cost function, at least not until some relatively high intensity is reached. Exceptions to this generalization can, however, be cited. In the classic legal case 1/ involving aircraft noise, noise from an airbase was held to have reduced the production of Causby's chicken farm.

I might interject at this point that the number of court cases that have resulted in compensation to those damaged by aircraft noise are, thus far, few in number, although they do attest to the fact that people are incurring real costs. Since 1955, about $2.0 million has been recovered in known airport noise cases, and many millions of dollars more are currently pending before the courts; about one-half billion in the Los Angeles area alone.

The theory upon which most recoveries have been based is that the plaintiff's property has been "taken" by the airport operator by necessitating flights over it; and that, under either the fifth or fourteenth amendment of the Federal Constitution, or under a similar provision of the State Constitution, he is entitled to be paid for the property taken. Considering that the legal prerequisites for "taking" exclude, in most cases, those adjacent to the flight path and those experiencing anything less than "substantial" interference; and, that the Court's criteria for computing damages probably do not reflect all costs, it seems evident that Court cases (and the magnitude of awards) are a poor indicator of the extent to which people are actually incurring costs as a result of aircraft noise.

1/ U. S. vs. CAUSBY (328 U.S. 256 - 1946)

In most situations relevant to the airport noise problem, noise constitutes a cost because it affects the utility functions of individuals. Aircraft noise near airports is intrusive and objectionable at subjectively determined levels and amounts. As such, it constitutes an economic, as well as a social cost, to society. In effect, aircraft noise reduces the willingness of persons to pay for the services of certain capital goods, particularly, residential properties. The diminution in the value of the services leads to a reduction in capital values, which ultimately constitutes the measure of constitutional damage or taking. This diminution in the value of capital goods, from what would otherwise be the case, is perceived from an individual viewpoint, even if not always evident in market transactions.

Airport Noise As An External Cost

From an economic viewpoint, the root of the conflict over airport noise is an "external" cost. By definition, an external cost exists when the production of a commodity or service by one economic entity necessarily imposes an unfavorable or unwanted effect on another entity, for which payment is not provided.

Two aspects of the meaning of externalities may be noted, by way of further explanation. One is that the term is more than simply descriptive of economic interdependencies. Almost any economic activity by one entity has an effect on other entities. When a manufacturer raises his prices, for example, a series of economic effects is induced. The important feature of most such activity is that the costs are borne (and the benefits received) by the decision-making entity. Externalities, on the other hand, are distinguished from other costs by the fact of nonpayment by the responsible entity, although it receives the benefits.

The other important aspect of the meaning of externalities is one of viewpoint. Externalities exist only in terms of a defined viewpoint, or locus of responsibility. The costs of airport noise borne by residents near airports are external from the viewpoint of the producers of air transport services.

These costs would be internalized, by definition, if they were transferred from residents near airports (by one means or another) to the air transportation industry. The costs would then be internal from the point of view of the industry.

Here the goal or criterion of "economic efficiency" can be applied. Simply stated, economic efficiency requires that all of the Nation's scarce resources be allocated to their most productive use. This kind of allocation is in theory normally achieved by the market. Efficiency is not achieved if, among other reasons, the prices of goods and services sold in the market do not reflect their actual production costs.

Market prices serve two purposes: as signals to consumers for purchasing, and as signals to producers on output, or demand. If the prices of some goods (or services) do not reflect their actual costs of production, for one reason or another (e.g., external costs), then more resources will be devoted to the production of these goods (or services) than would otherwise be the case. And this is the case in the production of air transportation services. If the services are sold at less than their actual costs of production; that is, absent the "external" costs of airport noise -- then air transportation production has an advantage over other industries (all of whose costs are internal) in competing for scarce productive resources. The conclusion is that the services provided by the air transportation industry should reflect their external costs in the interests of economic efficiency.

The Reciprocal Nature Of The Aircraft Noise Problem

The basic conflict over the external cost of airport noise involves two special groups. Social and economic costs are being imposed by the air transportation industry upon residents near airports. Economic costs are being imposed at least indirectly by residents near airports upon the air transportation industry. Both groups are special in the sense of being a small fraction of the total population and of the total economic activity in the United States.

The fact that two groups are in conflict is not of itself a sufficient reason for government intervention -- either in the form of restraining action or financial assistance. Looked at in the abstract, an external cost may simply be tolerated if it is not serious. When it is serious, as is the case with airport noise, agreements may be arranged between the conflicting groups involved to provide for compensation or restraints. Government intervention is warranted, however, when the cost in some sense is serious and the groups in conflict are incapable of reaching agreement.

When a government (at any level) intervenes in a problem area of external costs, it is appropriately concerned not simply with restricting the group responsible for the costs -- assuming the activity is not illegal. In all such cases, the government must be concerned with the unfavorable consequences of imposing restraints upon the group responsible for the costs, as well as the unfavorable consequences to those on whom the costs are being imposed. A unilateral approach to the airport noise problem, for example, would require only the imposition by government of restraints upon civil aviation. This approach fails to recognize that the unfavorable consequences of such action against civil aviation are also a matter of concern to government. Reducing costs of airport noise to residents imposes costs upon civil aviation, and directly and indirectly upon other groups up to and including the general public. In this sense, the problem is reciprocal. The equitable approach for government is to consider both sets of costs as marginal and total costs, and to choose courses of remedial and preventive action to equate the marginal costs and reduce total costs to a minimum.

Criteria For Determining Appropriate Levels Of Standards

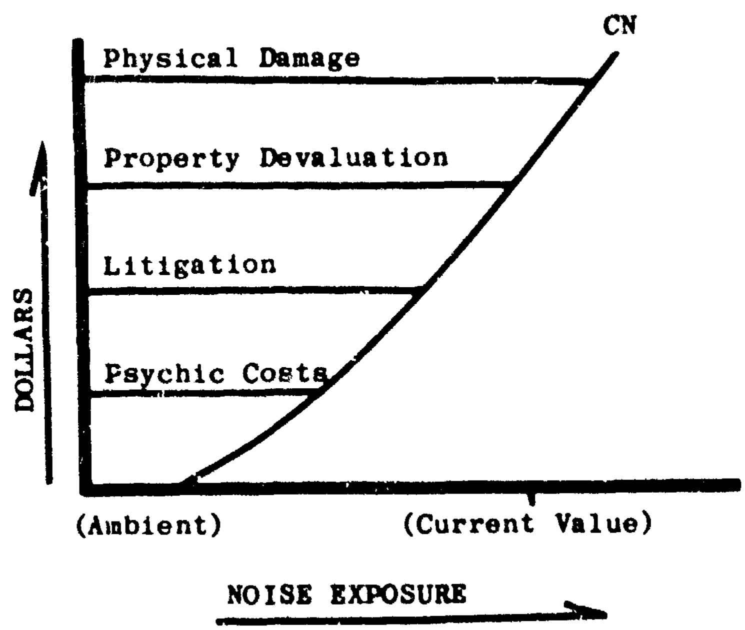
In the field of air transportation, it is clear that the government has powers which enable it to circumvent the market. However, there is no reason to suppose that restrictive regulations, made by a fallible administration, subject to political pressures and operating without any competitive check, will necessarily always be those which increase the efficiency and equity of the economic system. On the other hand, there is no reason why such government administrative regulations should not lead to an improvement in economic efficiency and equity if the methods by which government arrives at standards, and the rationale behind its decision-making, is sound.

Two lists would suffice for a rational setting of aircraft noise standards -- in one, all the changes necessary to bring about a given reduction in noise exposure and, in the other, all the consequences that result from such a reduction. If the items in each list could be assigned realistic dollar values, the list would represent two broad categories of costs. The first we could call the "cost of control" (to those producing the noise) and the second the "cost of noise" (to those perceiving the noise), since it represents the benefits foregone in the absence of controls.

By the way of illustration, the cost of noise might be represented by the curve in Figure 1.

FIGURE 1

TOTAL COST OF NOISE



The CN curve is the aggregate of all costs to those in the vicinity of airports resulting from aircraft noise. Unlike other pollutants, there are few direct aircraft noise costs or losses which can be easily or accurately measured and quantified. Noise does not damage paint, for example, as do some forms of air pollution. If so, the damage could be measured in terms of the cost required to repaint an affected house or other such structure (over and above that which might be incurred as a result of normal maintenance requirements). Neither does it endanger fish and wildlife as does water pollution where economic losses are easily identified. There is no evidence that aircraft noise results in measurable physical damage to humans working and residing in the vicinity of airports.

There are, however, some disaggregated indices of noise damage which, combined with good qualitative analysis and realistic assumptions, may be aggregated to produce usable data inputs for developing the curve. Some such indicies can be measured by market and transaction costs. Damage awards resulting from noise litigation cases and differentials in the rise and fall of real estate values in noise blighted areas are but two examples.

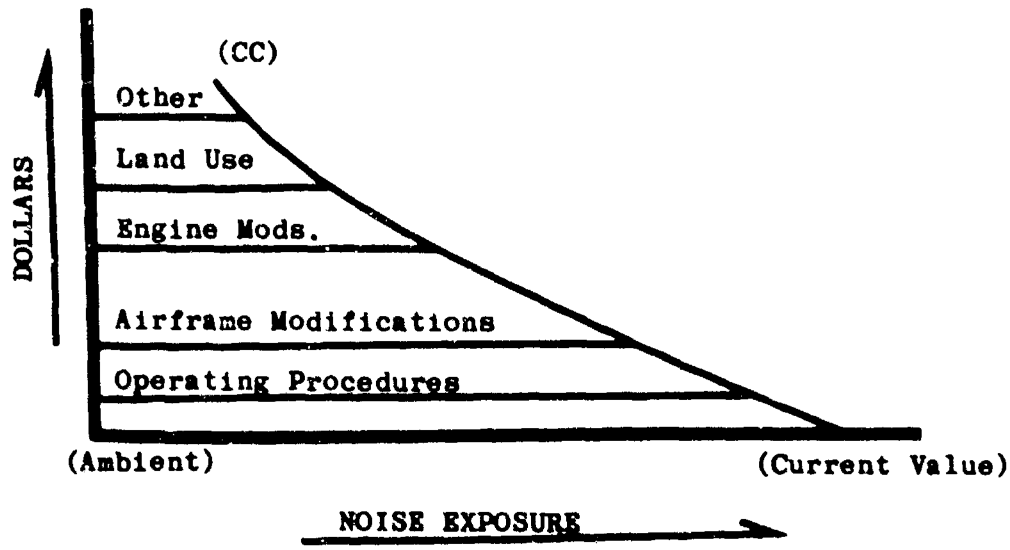
For the majority of noise costs, there are no market reflections whatsoever. The most important and difficult example of this type of loss is what might be called "psychic costs". This category includes everything from the distress of having a baby woken in the middle of the night to the irritation of having one's conversation disrupted by aircraft noise.

Quantitative analyses have generally ignored this category on the primary ground that it cannot be accurately measured. While this is true up to a point, it should be kept in mind that the organization and structuring of the problem in terms that are useful for measurement, and the clarification of issues that typically result from such an exercise may be of as much use to the decision-maker ad the measurements themselves. It also becomes important when one considers that federal involvement in the noise problem was prompted by an increasing number of complaints; and complaints, as previously mentioned, are poor indicators of costs deserving of compensation. Thus, we are making a conscientious and concerted effort to identify and quantify, to the extent possible, the relevant social costs of noise.

We are currently engaged in a number of socio-economic studies and surveys which will shed more light on the mechanics of quantifying social and phychic costs. Others are being planned for implementation in the near future.

FIGURE 2

TOTAL COST OF NOISE CONTROL



The cost of noise control curve, CC, in Figure 2 is composed of alternative actions which, in whole or in part, provide a means for alleviating the aircraft noise problem. The aggregate of these actions define the total curve.

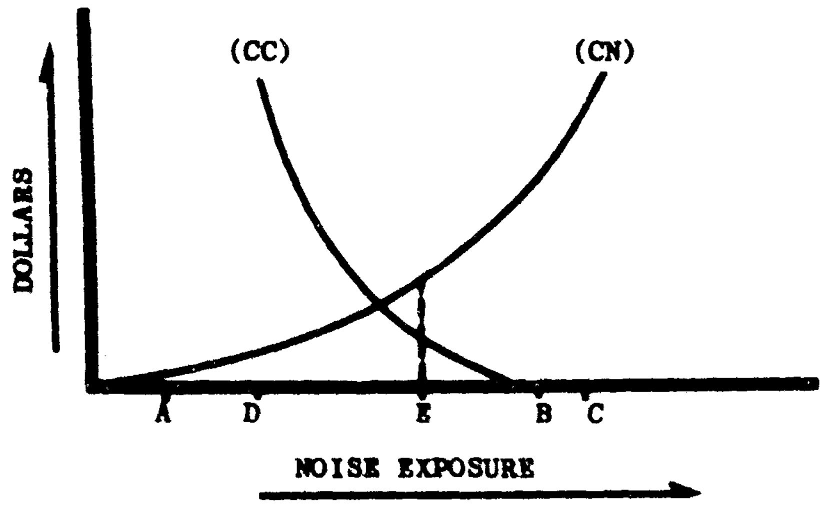
Within the current state-of-the-art, the following can be considered as major alternatives, and to form the cost of control curve:

1. Aircraft flight path and operational changes
2. Aircraft retrofit modifications
3. Engine retrofit modifications
4. New aircraft and engine design changes developed exclusively for noise abatement purposes
5. Airport changes
6. Land use changes
7. Structural soundproofing

Each of these alternatives can be quantified by means of direct measurement; that is, by establishing the incremental cost of implementing each alternative as a function of the corresponding incremental effectiveness of reducing aircraft noise exposure. And, of course, a great deal of research and development work is being pursued by both government and industry to define this curve.

The costs of aircraft noise control and the costs of noise are portrayed together in Figure 3.

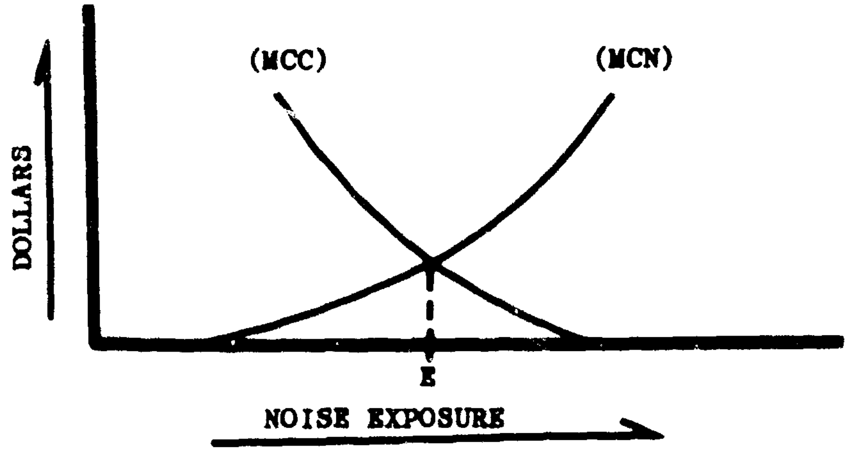
FIGURE 3



As the level of aircraft noise increases to some point A, the curve CN begins to rise, since people begin to incur costs as a result of aircraft noise. The curve CN may become nearly vertical at point C where physical damage results from exposure to noise. The curve CC is zero at some point B -- the noise level existing in the absence of abatement controls. As efforts are made to reduce noise, the costs of these efforts increase until the curve CC becomes vertical at some point D, where the state-of-the-art is reached and noise cannot be further reduced regardless of the money spent.

The best level at which to set a noise standard (or goal, in the case of reducing the noise exposure) is where both the costs of noise and the costs of control, taken together, are minimum -- (point E on Figure 3). Figure 4 shows the marginal cost curves, each of which indicates how the corresponding curve in Figure 3 changes for a small change in the noise exposure. The MCC curve has been plotted in the same quadrant as the MCN curve for convenience of presentation. Here, the appropriate standard is indicated by point E where the marginal cost of control (MCC) equals the marginal cost of noise (MCN). That is, where every dollar spent on noise control reduces the cost created by aircraft noise by an equal amount.

FIGURE 4



If measurements are to be useful within this analytical framework, they should possess certain characteristics. First, they must tell more than the current total costs of noise and of control; knowing only the current point on the curves in Figure 3 could be misleading. Informed decisions require a knowledge of current marginal costs which indicate the direction, if not the exact point, toward which policy should move. For example, at noise exposure level E in Figure 3, the cost of noise is higher than the cost of control. If money is spent to reduce the noise exposure level until both costs are equal, the combined costs would increase and be larger than the minimum combined costs shown at point E in Figure 4.

It is important also that measurements represent minimum costs. With respect to the cost of control, the standard will not be set correctly unless each point on the curve represents the minimum cost of achieving the implied reduction in noise exposure. The same is also true for costs of noise. If it is cheaper for the noise victim to move than to continue suffering, only the losses he would incur in moving should be included in the cost of noise curve. If this procedure is not followed, the standard could easily be set too low, considering the interest of the noise generator as well as those of the person who suffers from noise.

Point E (the equilibrium point of the marginal costs curves) will represent the appropriate standard (or goal for public policy) only if the cost of noise and of noise control curves measure and aggregate all relevant benefit and costs adequately. Realistically, of course, many important consequences cannot be measured in dollar costs so that good qualitative analysis must also be applied in the analytical process -- all of which, in the final analysis, is intended to complement (not replace) the experience, intuition, and judgment of the decision-maker.

The Assignment Of Cost Responsibility

I have thus far described, in general terms, something of the economic nature of the noise problem, the costs involved, and the role of quantitative economic analysis in aiding the decision-maker in selecting courses of action which can lead to an efficient and equitable solution to the noise problem. Such courses of action will necessarily involve the expenditure of funds to implement noise alleviation programs. The question can now be asked: Who should bear the costs of new programs to alleviate aircraft noise in the vicinity of airports and, if you will, STOL ports?

The legal liability for airport noise has, in a limited manner, been assigned to the airport operator (and the local government) by the United States Supreme Court in the Griggs case. It seems clear to me, based on the Griggs decision as a precedent, that the Federal Government will not have added financial responsibility for airport noise alleviation. The various congressional hearings leading up to the passage of Public Law 90-411 which directs the Federal Aviation Administrator to certify aircraft for noise also indicates that Congress does not intend that implementation of this legislation should result in federal financial preemption for noise damages.

In establishing the economic basis for assigning cost allocation responsibility neither the goals of economic efficiency or equity can be designated as the more important in any total sense, except by value judgment or the expression of personal preference. As previously established, the goal of economic efficiency is not achieved unless the prices of goods and services sold in the market reflect their actual production costs. The conclusion is that the services provided by the air transport industry should reflect their external costs, and this means imposing the cost of new programs to alleviate airport noise on the industry and ultimately on the air travelers and shippers.

The goal of economic equity is less neatly applied to compare alternative assignments of cost responsibility. The problem involved in its use is that there is no objective way of determining the optimum or fairest distribution of the Nation's income. One viewpoint to adopt is that the distribution of income provided by the market (in a total sense) is the optimum. There are, however, good reasons for rejecting this viewpoint; for example, the existence of monopoly elements and other imperfections in the market mechanism.

Although it cannot be demonstrated scientifically that any given incremental change in the Nation's income distribution would be more or less equitable than no change, government policy on this subject when choosing among operating programs need not be inconclusive. If cost responsibility for alleviating airport noise is to be assigned in whole or in part to the general public, its income in a real money sense will, of course, be less than would otherwise be the case. And, similarly, if the cost responsibility is assigned to the air travelers and shippers, their incomes will be reduced. It seems evident that air travelers and shippers cannot be regarded as economically deprived

groups. Thus, the economic welfare of the Nation will not have been improved in any sense by transferring income from the general taxpayers to these groups. Nor is there any basis in economic welfare for transferring income from the residents around airport to the air travelers and shippers -- as is the case when the residents bear without compensation the costs of objectionable airport noise. The conclusion seems warrented, subjective though it is, that the allocation of costs indicated by the criterion of economic efficiency need not be changed to achieve equity in the form of an improved distribution of the Nation's income.

Thus, the criteria of economic efficiency and equity indicate that those who gain from the use of the air transportation system compensate (by one means or another) those who incur cost in the provision of the system's services; whether the cost be in the form of fuel consumed, aircraft maintenance, pilot's salaries, or aircraft noise. These primary beneficiaries can be expected to pass on their added costs to the general public to the extent warranted by the market mechanism, without intervention by the Federal Government.

Summary

To briefly recapitulate:

1. The problem of aircraft noise is most notably one of conflict between two special groups. Social and economic costs are being imposed by civil aviation upon residents near airports. The basis for the conflict over airport noise is what economists call an "external" cost. The production of air transport services involves costs in the form of aircraft noise which are not now paid for by the producer, and are in this sense external to civil aviation. The problem is reciprocal, however. Reducing the costs of noise to the residents can impose cost on civil aviation. In the interest of equity, government must consider both sets of costs and choose action programs to equate as nearly as possible marginal costs and to reduce total costs.

2. Quantitative economic analysis plays an important role in choosing regulatory goals (or standards) which are fair and equitable considering the interests of both the producers and recipients of aircraft noise.

3. And, finally, the criteria of economic efficiency and equity requires that the net costs of alleviating aircraft noise be imposed on the industry and be borne ultimately by the air travelers and shippers.

CONCLUDING REMARKS

by

I. H. Hoover
Director, Office of Noise Abatement

Delivered at
Conference on STOL Transport
Aircraft Noise Certification

January 30, 1969

Federal Aviation Administration
Washington, D. C.

CONCLUDING REMARKS - STOL NOISE CONFERENCE

I. H. HOOVER

Now that we have reviewed several aspects of STOL aircraft development and operation which, in some way relate to the potential STOL noise problem, I would like to initiate FAA rulemaking activity in that field. I propose to do that in three steps:

1. Review the NPRM on noise certification of transport and turbojet powered aircraft released on January 6, 1969;

2. Discuss the environment in which that NPRM was developed and the differences which exist in relation to development of STOL noise control regulations; and

3. After a brief review of two concepts which have been considered within FAA, I want to enlist your assistance and participation in the development of a noise certification rule which will assure that the potential offered by STOL operations can be realized in a socially acceptable manner.

SLIDE 1 - The recently issued NPRM on noise certification proposes four fundamental actions:

1. The establishment of a noise objective above which actual levels must be justified (New Part 36);

2. The establishment of noise ceilings with tradeoffs (Appendix C);

3. The definition of procedures for conducting flight noise demonstrations (Appendix A); and,

4. The designation of a noise evaluation unit - EPNdB (Appendix B).

SLIDE 2 - The framework upon which the noise ceiling values are based is the original three-point concept proposed by the agency in September 1966, but with me change in the location of those points. An approach point is established one nautical mile from the threshol runway with the aircraft on a 3° glide slope (370' altitude). The sideline measuring location is 1,500' to the side of the runway centerline at that point after liftoff where the noise level is greatest. The takeoff measuring point is located 3.5 nautical miles from the start of takeoff roll. A thrust reduction is permitted to achieve required takeoff noise levels provided the aircraft has achieved an altitude of at least 1,000' and the thrust is not reduced below that level which will provide a 6% climb gradient thereafter.

SLIDE 3 - 80 EPNdB is identified on this slide as the floor noise level or "noise objective" as stated in the NPRM. This value represents a desirable goal for all aircraft and FAA will not pressure manufacturers to achieve levels below 80 EPNdB. Manufacturers are required to justify noise levels in excess of that value and they cannot exceed the ceiling values identified on the chart for sideline approach and takeoff. The value of 80 EPNdB was selected on the basis that it permitted face-to-face communications outdoors and with the sound attenuation of average residential construction, should permit normal indoor activities to be conducted with minimum interference. The requirement that all aircraft be as quiet as practical (exceed the noise objective no more than necessary) tends to be vague and difficult to administer, so we have included a list of the noise sources for each type propulsion system which the FAA expects manufacturers to address and minimize to the extent that it is "economically reasonable, technically practical, and appropriate to the particular aircraft type."

The ceiling noise levels shown on slide 3 vary with the gross weight of the aircraft and represent what FAA considers to be the lowest ceiling level that can be justified, considering the present technology available for noise reduction. The levels are well above any "acceptable level" but can be rationalized on the following basis.

We have a thriving commercial air transport industry recognized by society as a social and economic necessity. Since the social and economic benefits of air transportation are recognized and accrue to everyone in the community that the airport serves (and to everyone in the country in a lesser sense), it is reasonable that a relatively small minority living close to the airport be asked to pay a reasonable social cost to make the benefits of air commerce available to the total metropolitan community. In fact, it is more than reasonable; it is necessary. It is equally necessary that that same minority paying the social cost be, in some manner reimbursed, and the failure to provide such reimbursement is one of the roots of the present noise problem. This suggests that equity might be better served and the noise problem partially alleviated by reducing taxes in areas of high noise exposure (in relation to the total noise exposure - NEF) and that the lost revenues be made up partly by the total community which the airport serves and partly by some charge levied on the users of air transportation. Regardless of the presence or absence of equity near airports today, the fundamental point remains that a tradeoff between social costs and social and economic benefits is reasonable and necessary for the health of the existing air commerce industry and our society.

STOL noise control regulations are being developed in a different environment. The industry, in terms of large aircraft with high cruise speeds capable of city center to city center operations, does not exist and is therefore not recognized as essential by the public. STOL type operations presently being conducted by aircraft with light wing loadings having STOL operational capabilities do exist today, but a sudden interruption of those activities would not result in an urgent demand by the public that they be resumed. Further, they are sometimes conducted by aircraft with undesirable noise characteristics, which has not enhanced public anticipation of metropolitan STOL operations. With this situation, the public may oppose the development of urban area STOL ports and certainly will oppose the introduction of new noise sources in suburban areas if the noise levels are higher than considered "acceptable." Therefore, industry must develop aircraft that have noise characteristics considered in some sense "acceptable," if operators are to enjoy relative freedom from operational restrictions. As I understood today's technical presentations, it appears that STOL aircraft with acceptable noise characteristics at close distances are not on the horizon. That then requires that the concept of tradeoffs between social costs and social and economic benefits be instituted, if economically viable STOL operations are to be realized in the next few years. The challenge in public relations and education that this requirement presents to those contemplating STOL operations is not small, but for urban STOL ports can be met. In suburban areas with relatively low ambient noise levels, it is doubtful that a tradeoff of the necessary magnitude would be acceptable to the public.

SLIDE 4 - One noise certification concept that has been considered by FAA for STOL aircraft is the three-point concept proposed for more conventional aircraft, but with the measuring points located at much closer distances because of the operational characteristics of STOL aircraft and the requirement that only relatively small areas can be devoted to urban STOL ports. No noise levels have been considered to date, but discussing specific measurement locations permits the relative assessment of noise characteristics of proposed STOL aircraft concepts.

The three-point certification concept has the disadvantage of introducing arbitrary constraints into the aircraft design cycle, and conceivably more than one class of STOL port with varying distance criteria and runway lengths might be required. In any case, noise certification of an aircraft under this concept would not necessarily assure operations into all STOL ports and operational restrictions would probably still be necessary.

SLIDE 5 - Slide 5 shows a STOL port located along a river in an urban area where the noise sensitive communities are identified by the shaded zones. Areas relatively insensitive to noise are not shaded. This type of location

(which will probably support the first economically viable STOL city center operation) suggests a different approach to noise certification which I call the "operational restriction concept." Under this concept, noise certification of aircraft would consist simply of FAA validation of the aircraft's noise characteristics (noise footprints or contours generated by the aircraft at different weights and at a variety of temperatures, wind conditions, and altitudes). An aircraft would then be permitted to operate from any STOL port where it would not exceed some defined noise level at the edge of the nearest noise sensitive area. On slide 5, I have shown the noise contour of an aircraft operating in one direction. If the finger of noise sensitive area projecting in toward the STOL port at one end were converted to noise compatible usage, two-way operations would be permitted, and aircraft generating even slightly higher noise levels than that shown, could be accepted into the STOL port. This operational restriction concept is very flexible, and further provides incentives for manufacturers to design the quietest possible aircraft so that they can get into the largest number of STOL ports, and for STOL port developers to locate in or achieve the largest area insensitive to noise so that they can be served by the largest possible STOL aircraft. No "defined noise level" is proposed, however, the 80 EPNdB noise objective previously proposed suggests itself as such a level. In urban areas with high ambient noise levels, it might be permissible to use some increment above the ambient noise level; however, this presents a danger to the suburban STOL port since its neighbors might insist on that same increment above their low ambient noise level as their ceiling.

I wish to conclude by asking you to do two things:

1. Discuss the problems of STOL noise certification and operation within your companies and industry; and,

2. Forward to FAA directly or through your trade organizations, your suggestions on what type of certification concept will meet our common aims. Also, please indicate your willingness to participate in a task force whose job will be to develop and recommend to the Administrator a draft rule which, hopefully, he can propose to the public in a Notice of Proposed Rulemaking for comment by all interested parties.

1. ESTABLISHES A NOISE OBJECTIVE ABOVE WHICH ACTUAL LEVELS MUST BE JUSTIFIED.

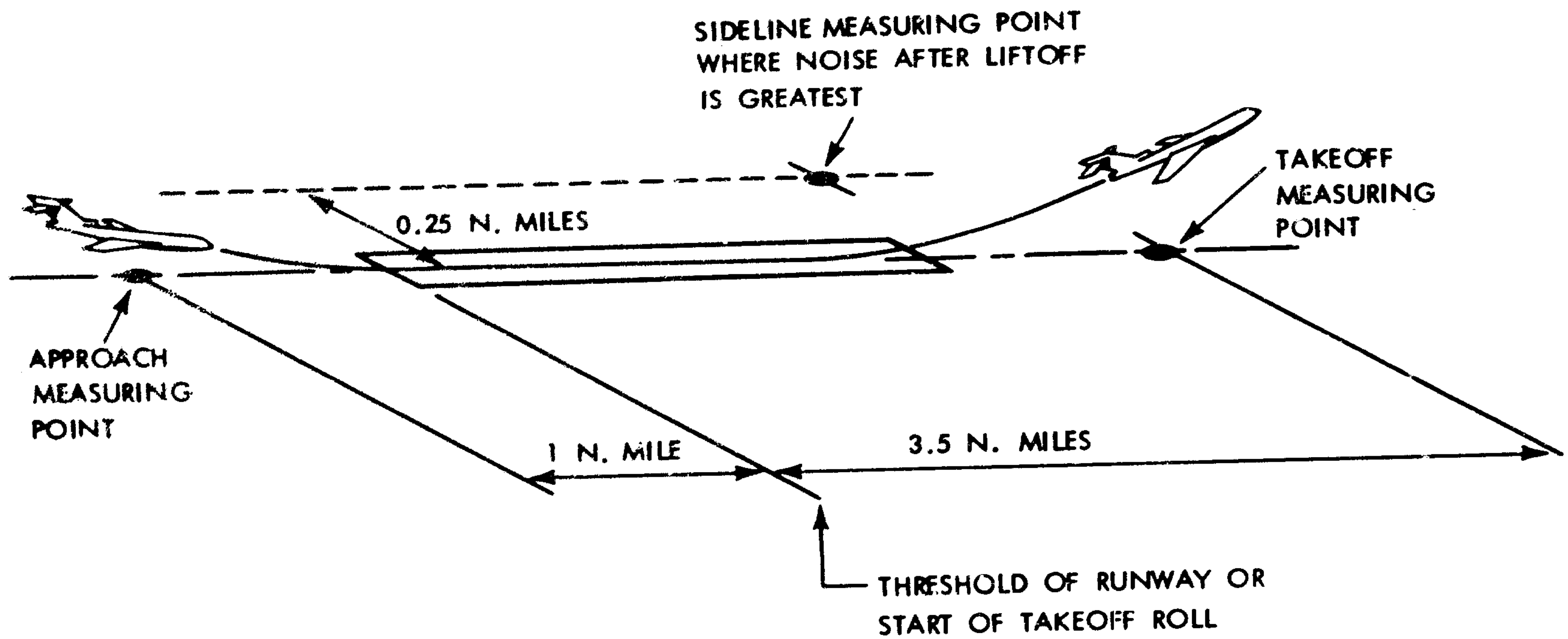
2. ESTABLISHES LEVELS "NOT TO BE EXCEEDED" WITH FLEXIBLE TRADEOFFS.

3. DEFINES PROCEDURES FOR CONDUCTING FLIGHT NOISE DEMONSTRATION.

4. DESIGNATES NOISE EVALUATION UNIT.

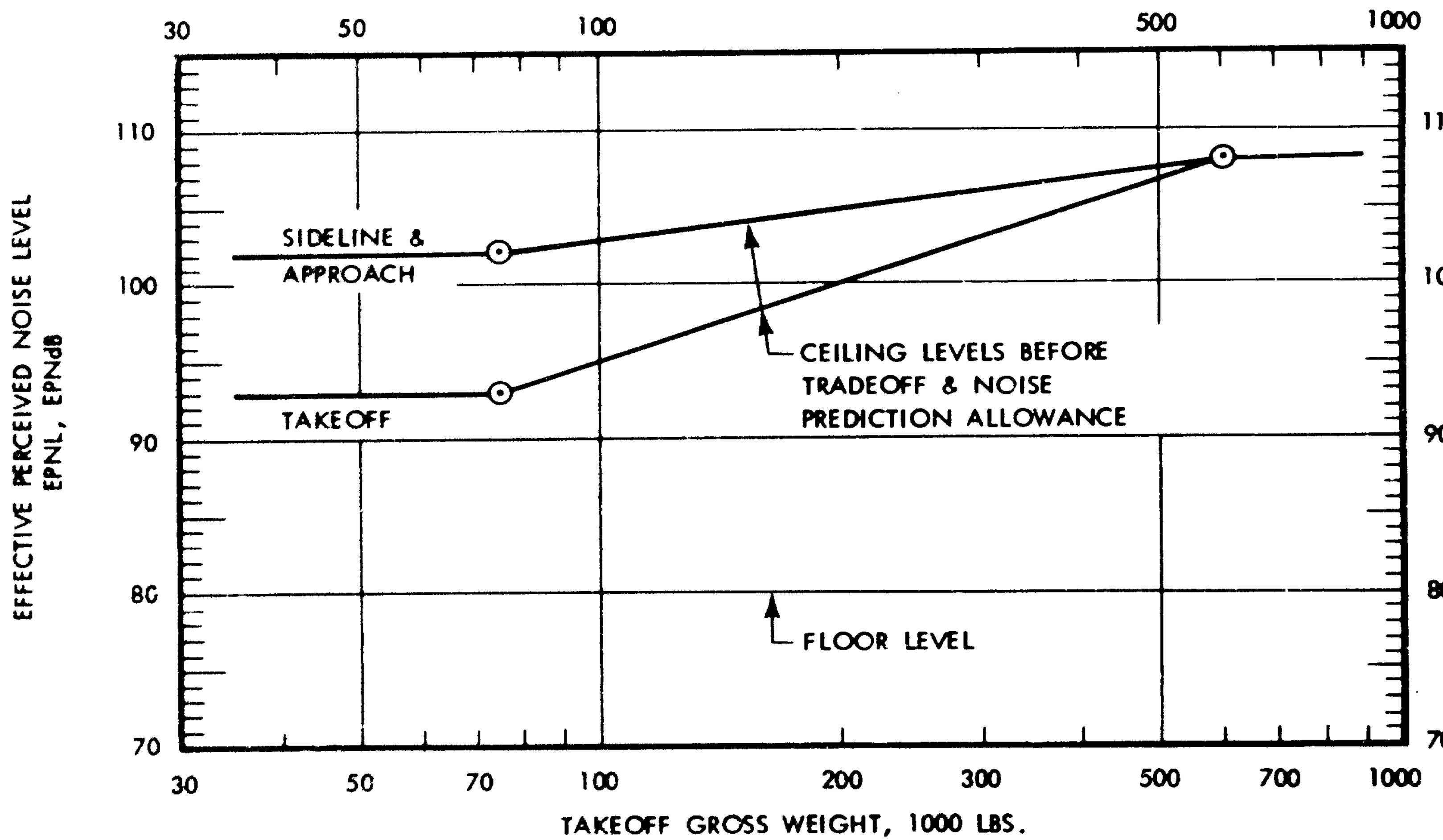
SLIDE 1

NPRM FOR SUBSONIC TRANSPORT AND TURBOJET AIRPLANES



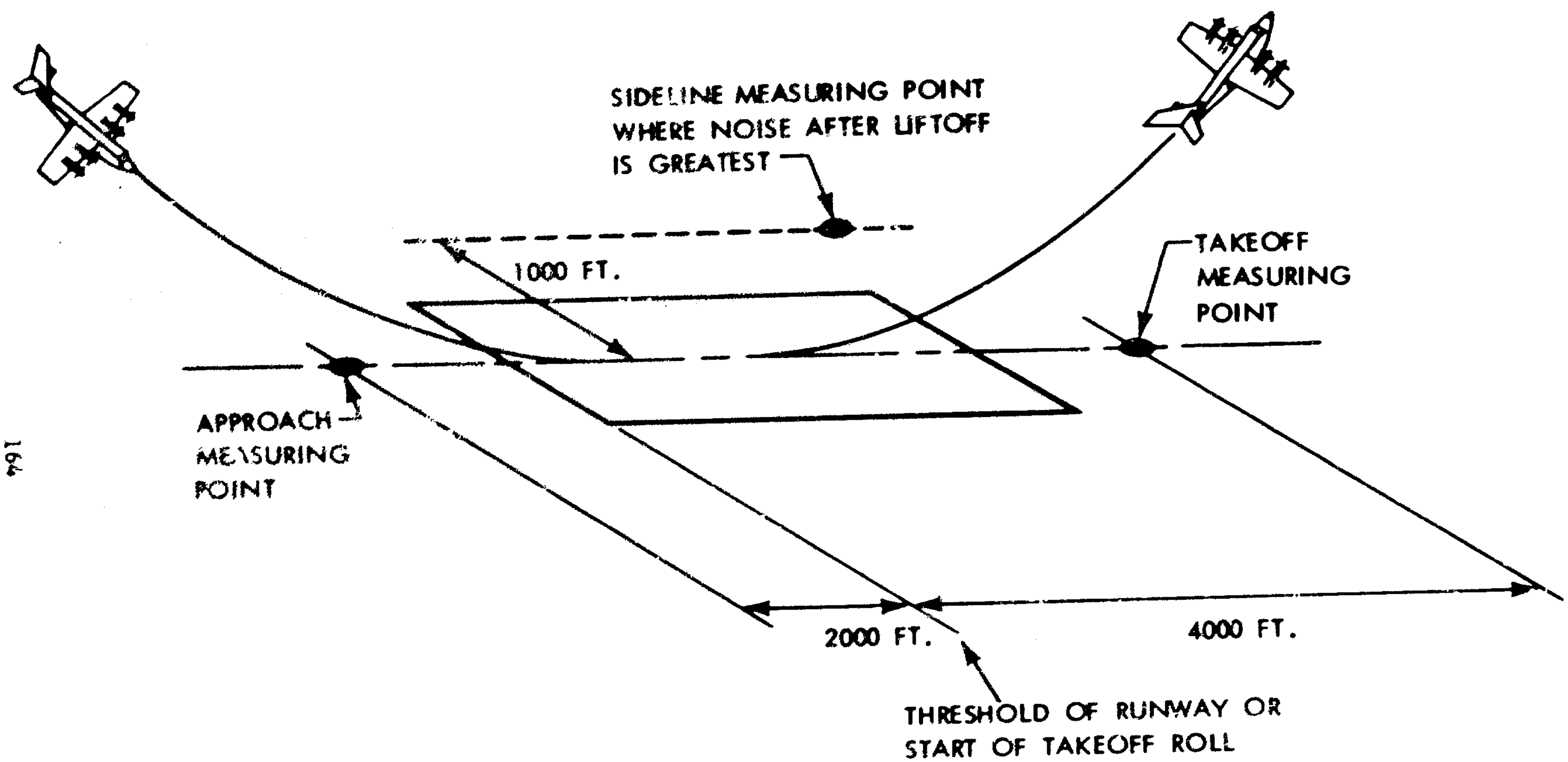
SLIDE 2

NOISE MEASURING POINTS FOR AIRPLANE TYPE CERTIFICATION



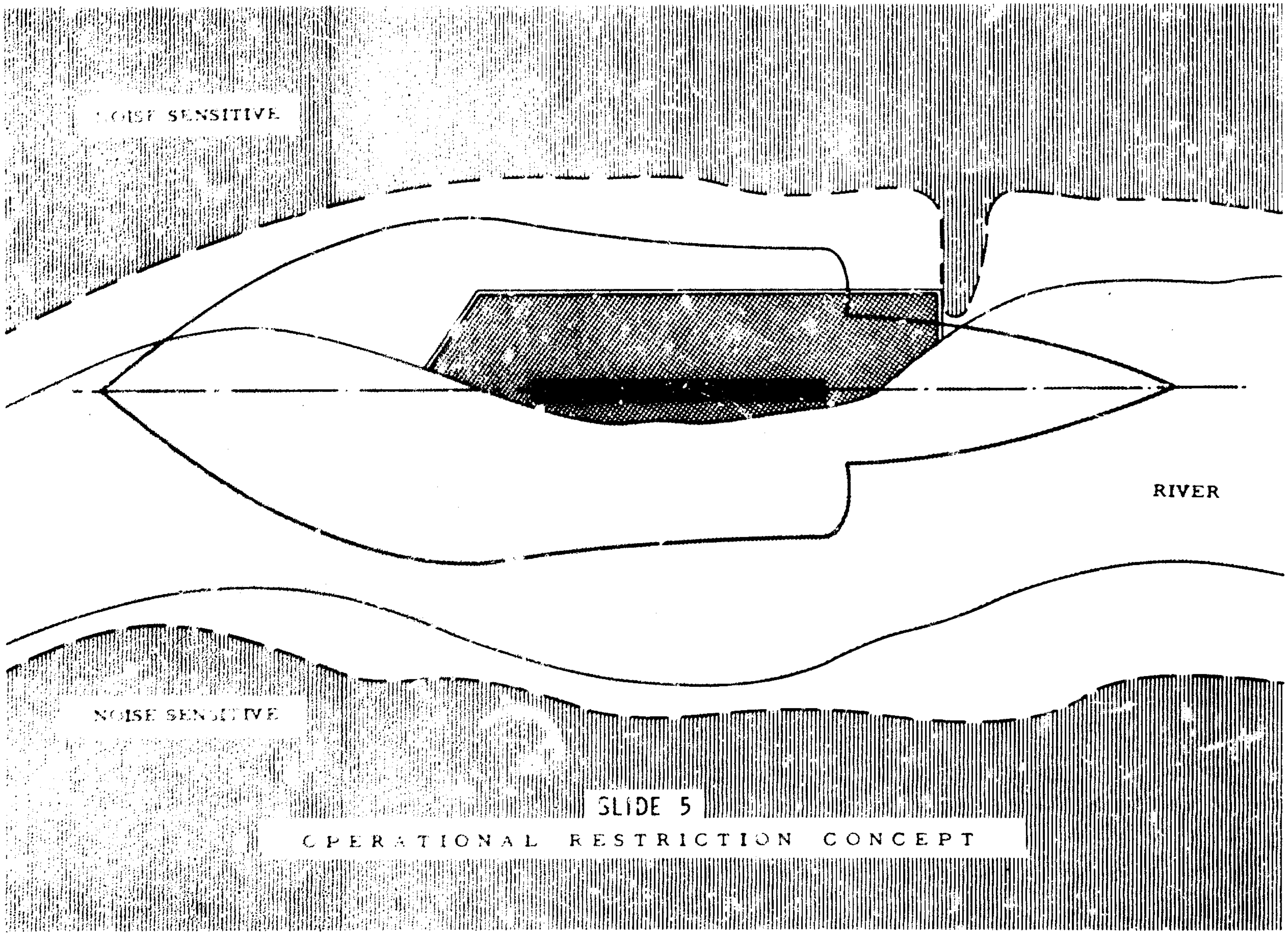
SLIDE 3

NOISE LEVELS FOR THREE-POINT CERTIFICATION CONCEPT



SLIDE 4

NOISE MEASURING POINTS FOR STOL AIRPLANE TYPE CERTIFICATION


NOISE SENSITIVE
RIVER
NOISE SENSITIVE
SLIDE 5
OPERATIONAL RESTRICTION CONCEPT

APPENDIX A

STOL CONFERENCE ATTENDEES

Aiken, W., of NASA
Aldridge, Seth, of Convair
Allcock, A. W. R., of the British Embassy
Argerakis, Alexander N., of CAB

Ballentine, J. R., of Lockheed-Georgia
Barnett, C., of CommuterCenters, Inc.
Barsony, S., of the Department of Transportation
Bates, George, of FAA
Becker, W., of ATA
Bianchini, G. V., of General Motors Corp.
Bonneau, N., of VACL
Bornarth, Robert, of AOPA
Brewer, J. D., of NASA
Brines, Gerald L., of Pratt & Whitney
Bristol, Carl W., of Pratt & Whitney
Brown, B., of the British Aircraft Corp.
Buller, F. H.
Burger, R. J., of NAS
Buttion, T. R., of Eastern Air Lines

Caldwell, J. P., of McDonnell-Douglas
Callaghan, T. P., of Mass. Port Authority
Calta, L. L., of PONYA
Cleveland, William, of Miami International Airport
Close, W. H., of the Department of Transportation
Compton, J. S., of New York Airways
Constantz, J., of Florida Aviation
Cornell, W. G., of G. E.
Coykendall, R. E., of United Air Lines
Curry, R., of Garrett Corp.
Curtis, W. M., of Fairchild-Hiller

Denn, R. J., of Garrett Corp.
Downes, Wm. C., Commissioner of Aviation, City of Chicago
Dutton, Benson L., of HEW

Earle, R. V., General Motors Corp., Allison Div.
Edwards, J. B., of Handley-Page
Elwell, R., of Pan Am
Emerson
Englebart, W. D.

Fairbanks, D. C., of DeHavilland - Canada
Feldman, Joan, of American Aviation
Fennell, L. J., of Ministry of Technology, England
Fitzsimmons, R. D., of Boeing
Flemming, M., of Dornier, Germany
Folson, S., of Pan Am
Foster, Charles, of the Department of Transportation
Fowler, John R., of National Academy of Science

Getline, G. L., of General Dynamics
Good, William, of Kelsey-Hayes Co.
Grebil, J. N., of the French Embassy

Hall, Donald, of Hamilton-Standard
Hall, Stephen, of Pratt & Whitney
Hancock, R. N., of LTV
Hintze, C., of CAB
Hoekstra, H. D., of FAA
Hoffert, P., of Germany
Hoban, J., of FAA
Howlett, Dr. D. P., of Hawker-Siddeley, England

Kappus
Kindle, H. C., of G. E.
Kohn, A. C., of G. E.
Krentz, J., of NASA
Kruk, John, or Piper

Lee, Robert, of G. E.
Liff, B., of Kaman Corp.
Lightfoot, Ralph B., of Sikorsky
Lockwood, B. J., of Los Angeles Dept. of Airports
Lott, M. A., of FAA
Lowry, R. E., of Allison

Marks, M. D., of McDonnell-Douglas
Massey, J. W., of AiResearch of Phoenix
McCann, J. C., of Pratt & Whitney
McPike, A. L., of Douglas Aircraft
Meek, J. W., of ALPA
Merkin, A., of NASA
Metzger, Bruce, of Hamilton-Standard, UAC
Miller, S. S., of Environmental Science & Technology
Morgan, Dr. W. R., of G. E.
Munch, Lee, of Wyle

Ollerhead, John, of Wyle

Paullin, Robert L., of the Department of Transportation
Potter, S. M., of New York City EPA
Prew, H. E., of New York City - Grumman

Ransone, R. K., of American Airlines
Roberts, Thomas H., Metro Washington Council of Governments
Romer, H., Department of Air Pollution Control - New York
Rosen, George, of Hamilton-Standard
Runnals, R. L., of G. E.
Rupert, Richard E., of Wyle

Schaerer, Dr. Ernst, of Switzerland
Scharr, R. L., of Aerospace Industries
Schlegel, Ronald G., of Sikorsky
Scott, David H., Experimental Aircraft Association
Slade, Robert, of the British Embassy
Snodgrass, J. C., Jr., of Aerospace Industries
Stalder, John, of North American Rockwell
Spelina, J., of ICAO - Canada
Spurgeon, C. C., of the Department of Transportation
Staubach, Richard L., of Pratt & Whitney
Stokes, Peter, of Rolls Royce in New York
Strok, H. J., of ATA
Strunck, James, Assistant Corp. Counsel, Chicago
Sullivan, Philip J., of Lockheed Aircraft
Swanson, R. B., of Helio Aircraft Corp.

Tatum, Edgar F., of Pratt & Whitney
Taylor, H., of American Aviation Publications
Tedrick, R. N., of AiResearch of Phoenix
Thompson, J. R., of Lockheed-California
Thurber, Robert, of HUD

Uffen, R. P., of DeHavilland
Unosson, Per U, of SAAB - Sweden

Weaver, C. L., of FAA
Wetmore, W. C., of Aviation Week
Williams, C. H., of the Department of Transportation
Williams, N. B., of Lockheed-California
Wohl, B., of American Airlines
Woo, John, of Airborne Instruments

Zigan, S. J., of G. E.

APPENDIX B

CONFERENCE ON STOL TRANSPORT
AIRCRAFT NOISE CERTIFICATION

January 30, 1969
FAA Auditorium
9:30 A. M.

I - Welcome by Associate Administrator for Operations

II - STOL Development

A. The FAA Role in STOL Development
Mrs. Joan B. Barriage - FAA Aircraft Development Service
B. Noise Study of Transport Designs
Wallace H. Deckert - NASA Ames Research Center

III - STOL Noise Generation and Propagation

A. Noise Source Characteristics of Engines and Propellers
Harvey H. Hubbard and Domenic J. Maglieri - NASA Langley Research Center
B. Characteristics of Noise Generated by Ducted Propellers and Fans
David H. Hickey - NASA Ames Research Center

IV - STOL Operational Considerations

A. STOL Noise Abatement Operational Considerations
Alder P. Betti and Paul D. Wilburn - FAA Flight Standards Service
B. The STOL Port and Its Environment
George L. Buley - FAA Airports Service
Myles H. Reynolds - FAA Air Traffic Service

12:00 - 1:30 - Lunch

V - Noise Reduction Techniques

A. Some New Developments in the Noise Reduction in Ducted Propellers and Fans
David H. Hickey - NASA Ames Research Center
B. Noise Reduction Techniques for Engines and Propellers
Domenic J. Maglieri and John L. Crigler - NASA Langley Research Center

VI - Aircraft Noise Certification

A. Noise Evaluation for Certification
William C. Sperry - FAA Office of Noise Abatement
B. Economic Aspects of Noise Certification
George P. Hunter - FAA Office of Noise Abatement
C. Notice of Proposed Rulemaking and Standards for STOL Transports
Isaac H. Hoover - FAA, Director of Office of Noise Abatement
Richard W. Danforth - FAA Office of General Counsel

VII - Open Comment and Discussion